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ASPEN IN THE CENTRAL ROCKY MOUNTAIN REGION

By

FREDERICK S. BAKER, Forest Examiner, Forest Service

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By Frederick S. Baker, *Forest Examiner, Forest Service*

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INTRODUCTION

The detailed studies reported in this bulletin were carried out chiefly on the Ephraim Canyon watershed of the Manti National Forest in central Utah. (Pl. I.) The results, however, in a very general way, cover the aspen in the entire central Rocky Mountain region, including Wyoming, Colorado, Utah, Nevada, southern Idaho, and a little of northern Arizona and New Mexico. More general observations made personally by the writer throughout Utah, southern Idaho, and western Wyoming, indicate that the results obtained in central Utah are generally applicable throughout that entire region. The climatic, topographic, and ecological simi-

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Note.—The writer wishes to acknowledge the valuable assistance rendered in this work by the parallel studies, on the subject of decay in aspen, conducted in the same region under the direction of Dr. E. P. Meinecke. The unpublished manuscript report of this work was placed at the writer's disposal. The discussion of the pathology of aspen, down to and including Table 7, page 14, is based on the report of Doctor Meinecke.

larity of Colorado, especially the "west slope," indicates that the conditions there, as far as aspen is concerned, are virtually identical with those of the central Utah region.

DISTRIBUTION

Aspen (*Populus tremuloides* Michx.)[1] is the most widely distributed broadleaf tree of North America. Its range extends from southern Labrador to Hudson Bay (southern shores) and northwestward to the Mackenzie River, near its mouth, and Alaska (Yukon River); southward to Pennsylvania (mountains), northeastern Missouri, southern Nebraska, and throughout the western mountains to northern New Mexico and Arizona and central California, Lower California (San Pedro Martir Mountains), and Mexico (mountains of Chihuahua) (*14*).[2]

In the mountains of the western United States aspen is found widely distributed at middle elevations. It is of slight importance throughout the greater part of this area, however, becoming a prominent component of forests[3] only in Utah, Nevada, Colorado, and parts of northern New Mexico, and Arizona (fig. 1).

In either region it is impossible in forest management to consider aspen independently of the associated conifers. In the East this competition makes aspen an especially ephemeral type, occupying, as a rule, recent burns. In the West aspen appears to be permanent over large areas owing to the lesser aggressiveness of the conifers; but even here there is always a successional tendency working in aspen stands, tending more or less successfully to transform them into conifer stands.

Silvicultural practices can aid or hinder this natural process, and in every aspen forest under management the silvicultural treatment must be considered first of all from the standpoint of its effect upon the related conifers as well as upon the aspen. Accordingly, this bulletin, while dealing with aspen primarily, includes much parallel work on conifers associated with aspen, in order to be of value in the solution of this most fundamental problem of the management of aspen areas.

The essential uniformity of aspen throughout its wide range is emphasized by comparing the results of these studies with earlier work on aspen in New England (*15*). It is found that while growth is more rapid in New England, deterioration and decay take place earlier, so that the maximum and average sizes are about the same in the two regions and the stands are very similar.

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[1] Other names in common local use are quaking asp (sometimes written quakeenasp), asp, quakers, and mountain asp. The scientific name *P. tremuloides aurea* (Daniels) has been proposed to apply to the western aspen, the chief distinguishing character being the striking golden color of the leaves in the fall. Tidestrom recognizes this variety as a distinct species, *P. aurea* (Tidestrom). *P. cercidiphylla* (Brit.) is a tree similar to common aspen, except as to leaf characters. It has been found only in Upper Hoback Basin, Wyo.

[2] The italic numbers in parenthesis, occurring throughout the bulletin, refer to literature cited in the bibliography on p. 46.

[3] The aspen type has been defined by the Forest Service (1913) as: "A stand containing 60 per cent or more of aspen, often nearly pure, but also with various conifers in mixture. Areas with a temporary type of aspen . . . . should be classified . . . . according to that stage of type development which will be used in management." Principal associated trees include western yellow pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga taxifolia*), lodgepole pine (*Pinus contorta*), and Engelmann spruce (*Picea engelmanni*).

Aspen is found throughout this region at its lowest altitudinal limit as a scrubby tree along creeks flowing through the chaparral or western yellow pine types. As altitude increases the aspen spreads out from the creek banks to moist pockets in the upper western yellow pine and chaparral types and then to flats and moist slopes in the Douglas fir zone, while in the highest spruce-fir zone it usually occupies west and south slopes, although its quality is poor in such places. It may go even to timber line as a stunted shrub. The tree reaches its best development, however, near the lower limit of Engelmann spruce and, except where it enters into competition with lodgepole pine, often covers large areas with stands of high quality.

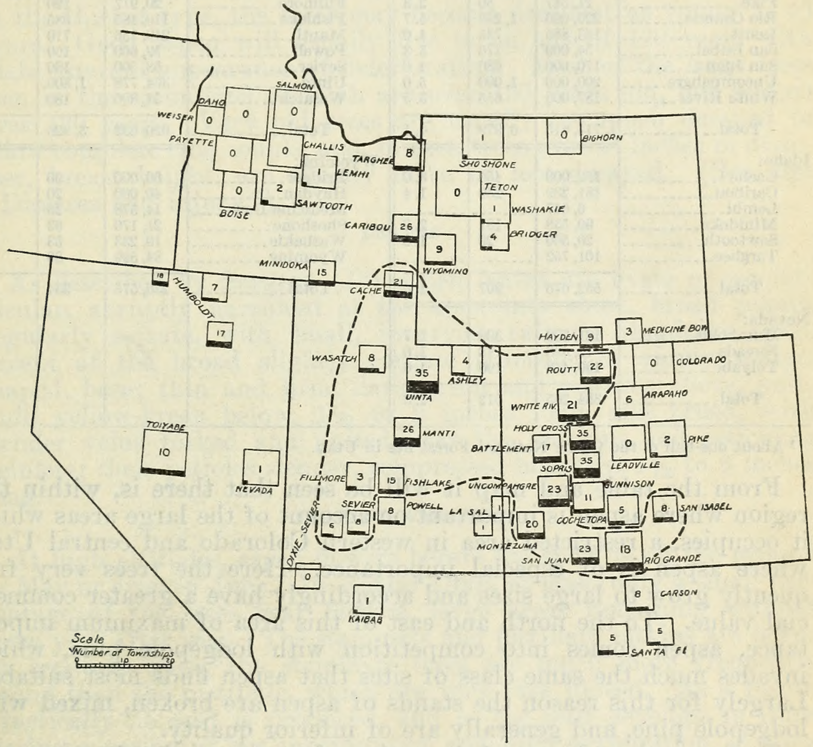

FIG. 1.—Distribution of aspen throughout Utah, Nevada, Colorado, and parts of northern New Mexico and Arizona. This map shows the relative areas and general location of the different national forests of the central Rocky Mountain region, together with the percentage of each national forest area covered by the aspen type. Since areas smaller than 20 acres are disregarded in compiling type acreages, forests showing no aspen type may have considerable amounts widely scattered in small patches among other types

The areas covered with aspen and the amount of aspen cordwood found on the different national forests within the central Rocky Mountains and intermountain region are shown in Table 1. Growth is considered important in all forests which show average stands of more than 3 cords per acre.

TABLE 1.—*Aspen areas and stand*

State and forest	Area	Stand	Stand per acre
	Acres	*1,000 cords*	*Cords*
Colorado:			
Arapaho	36, 000	50	1. 4
Battlement	113, 400	395	3. 5
Cochetopa	41, 700	40	1. 0
Colorado	4, 000	5	1. 2
Gunnison	101, 890	164	1. 6
Holy Cross	210, 500	526	2. 5
Leadville	8, 000	4	. 5
Montezuma	162, 693	1, 241	7. 6
Pike	21, 547	50	2. 3
Rio Grande	220, 000	1, 258	5. 7
Routt	183, 885	735	4. 0
San Isabel	54, 000	176	3. 3
San Juan	170, 000	680	4. 0
Uncompahgre	200, 000	1, 000	5. 0
White River	187, 000	655	3. 5
Total	1, 714, 615	6, 979	4. 1
Idaho:			
Cache[1]	152, 000	456	3. 0
Caribou	181, 239	250	1. 4
Lemhi	6, 647	--------	--------
Minidoka	90, 538	181	2. 0
Sawtooth	20, 500	20	1. 0
Targhee	101, 752	--------	--------
Total	552, 676	907	1. 6
Nevada:			
Humboldt	181, 239	309	1. 7
Nevada	12, 608	13	1. 0
Toiyabe	190, 418	190	1. 0
Total	384, 265	512	1. 3
New Mexico:			
Carson	76, 000	--------	--------
Santa Fe	75, 000	--------	--------
Total	151, 000	--------	--------
Utah:			
Ashley	35, 300	176	5. 0
Dixie	--------	15	--------
Fillmore	20, 917	120	5. 7
Fishlake	110, 485	585	5. 3
Manti	219, 156	710	3. 2
Powell	59, 600	160	2. 7
Sevier	58, 500	180	3. 1
Uinta	364, 778	1, 800	4. 9
Wasatch	51, 896	180	3. 5
Total	920, 632	3, 926	4. 3
Wyoming:			
Bridger	60, 000	90	1. 5
Hayden	40, 000	20	. 5
Medicine Bow	14, 573	19	1. 3
Shoshone	21, 170	63	3. 0
Washakie	10, 233	53	5. 2
Wyoming	84, 599	89	1. 1
Total	230, 575	334	1. 4

---

[1] About one-half of the Cache National Forest lies in Utah.

From the table and map it will be seen that there is, within the region where aspen is important on account of the large areas which it occupies, a restricted area in western Colorado and central Utah where aspen is of especial importance. Here the trees very frequently grow to large sizes and accordingly have a greater commercial value. To the north and east of this area of maximum importance, aspen comes into competition with lodgepole pine, which invades much the same class of sites that aspen finds most suitable. Largely for this reason the stands of aspen are broken, mixed with lodgepole pine, and generally are of inferior quality.

To the south and west of the region of maximum development, the aspen, which is by nature a northern species, meets with climatic conditions that appear to be less favorable to it.

Within the whole region where aspen is of secondary importance the ephemeral nature of the type is rarely questioned and its limitation to burns or other open areas where the original coniferous timber has been destroyed is readily apparent in most cases. But within the central region, where aspen is of greatest importance and value, it presents many characteristics of a permanent climax forest type. While this permanence is probably more a matter of superficial appearance than actuality in most cases, it is necessary in much of this region, as far as forest management is concerned, to treat aspen as a permanent type because of the length of time that will be required to effect a transformation into the coniferous type.

THE TREE

Aspen is a tree of extremely variable development in the Rocky Mountain region, ranging from little more than a shrub on sites at high altitudes and northern latitudes to trees that may attain a diameter of 38 inches at breast height, and a height of 90 feet in exceptional cases. (Pl. II.) In general, the trees in the intermountain region range from 8 to 14 inches diameter at breast height at maturity, with heights between 50 and 60 feet.

The age of aspen varies greatly with site. Single trees as old as 200 years, and whole stands as old as 150 years still existing in even-aged form, have been found on first-class sites. On other sites, in the thicket type, the trees may become decadent as young as 40 years. Good aspen will usually live to an age of 120 years with little external appearance of deterioration. Most of the large trees seen in the mountains of Utah are over 100 years old, but seldom over 130 years. Very old trees are usually too much decayed to allow complete ring counts, and, in fact, trees over 14 inches in diameter, breast height, are usually more or less decayed. (See also "Diseases and injury.")

LEAVES

As described by Sargent (*13*) aspen leaves are ovate or semiorbicular, abruptly narrowed at the apex into short, broad points, regularly serrate, with small, incurved, callous, glandular teeth, except at the broad slightly cordate truncate, or rarely wedge-shaped, base; thin and firm, dark green and lustrous above, pale, dull, yellow-green below, 1½ to 2 inches long, and broad, with slender veins forked and united near the margins and reticulate veinlets; their petioles slender, compressed laterally, 1½ to 3 inches long.

FLOWERS AND SEED

At high altitudes, aspen flowers before the snow is off the ground in May or even in June. In central Utah, at least, only a small percentage of the trees bear flowers, large areas remaining without them year after year. The staminate and pistillate catkins are borne on separate trees; the staminate trees are much more frequently found than the pistillate, which are very rare indeed. As a result, practically no seed is produced, and as the seed develops in June during a period of low precipitation and high evaporation, it often dries before it is mature. The viability of the seed is low, and as the seed bed is dry and unfavorable at the time of dispersal, reproduction by seed is unknown in this region. It may, of course, take place to a very limited degree at rare favorable intervals (*2*).

According to Sargent, the flowers are formed in aments 1½ to 2½ inches long, the pistillate being 4 inches long at maturity, their scales deeply divided into 3 to 5 linear acute lobes fringed with long soft gray hairs; disk oblique, the staminate entire, the pistillate slightly crenate; stamens 6 to 12; ovary conical, with a short, thick stype and erect stigmas thickened and club-shaped below and divided into linear diverging lobes. Fruit matures in May or June, oblong conical, light green, thin walled, nearly one-fourth inch long, seeds obovate, light brown, about one thirty-second inch long.

FORM

Aspen is a full-boled tree, having excellent form on the best sites but deteriorating into a crooked shrub on poor sites. The form of the tree is not constant, but changes with height although not with diameter, becoming fuller boled as height increases, as indicated by the absolute breast-height form quotient (diameter inside bark at a point halfway between breast height and the top of the tree divided by diameter, breast height, inside bark). This is expressed as follows: At a height of 40 feet the form quotient is 0.64; at 50 feet, 0.64; at 60 feet, 0.65; at 70 feet, 0.67; at 80 feet, 0.73.

Mature aspen 12 to 14 inches in diameter at breast height and 50 feet high has a fuller bole than any of the conifers associated with it except white fir, as indicated by its form quotient of 0.64 for 50-foot aspen. The quotient for Englemann spruce, alpine fir, and Douglas fir is 0.62; that for white fir is 0.65. In amount of clear-length aspen is extremely variable, although as a rule in fully stocked stands the crown is limited to a mere wisp of branches in the top, with dry branches extending down perhaps 10 feet. The twigs die early and soon break off in good dense stands; in poor sites they are more persistent, grow larger, and occupy more of the bole of the tree, giving it a dark, dirty, unkempt appearance, in striking contrast to the smooth trunks of thrifty trees. Typical conditions of this sort on sites 1, 3, and 5 are shown in Plates III and IV.[4]

Pronounced stump swelling is shown in aspen at an early age, amounting to as much as an inch at the base of trees of 8-inch diameter breast high. By the time the breast-high diameter is 16 inches the swell at stump height is nearly 2 inches. It begins to affect diameter-breast-high measurement directly when the latter reaches 10 inches, at 16 inches contributing as much as half an inch to this diameter.

The relation of diameter to total height varies with sites—the poorer the site the shorter the trees of a given diameter (Table 2).

TABLE 2.—*Average height of aspen of different diameters, on sites 1 to 4*

Diameter breast height	Total height				Diameter breast height	Total height			
	Site 1	Site 2	Site 3	Site 4		Site 1	Site 2	Site 3	Site 4
	Feet	*Feet*	*Feet*	*Feet*		*Feet*	*Feet*	*Feet*	*Feet*
4 inches	40	35	32	30	14 inches	78	71	61	--------
5 inches	46	41	36	34	15 inches	79	72	62	--------
6 inches	51	46	41	37	16 inches	80	73	62	--------
7 inches	57	51	45	39	17 inches	81	74	--------	--------
8 inches	62	56	46	41	18 inches	81	74	--------	--------
9 inches	66	59	51	43	19 inches	82	74	--------	--------
10 inches	70	63	54	45	20 inches	82	75	--------	--------
11 inches	73	66	57	46	21 inches	83	75	--------	--------
12 inches	75	68	58	48	22 inches	83	75	--------	--------
13 inches	76	70	60	--------					

BARK

The bark is one of the striking characteristics of the aspen tree, it being smooth, thin, and white or yellowish, except on larger trees, where it becomes dark and furrowed toward the base. This change is brought about sometimes on relatively small trees by sheep nibbling the lower bark. The thickness varies regularly with diameter, except near the base of the tree, where the bark is always relatively thicker than it is higher up, and increases in thickness more rapidly especially when the trees are 12 inches in diameter or over and furrowing and development of a dark, ridged bark begins to take place.

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[4] See Table 6, p. 13, for criterion of sites.

Bark, usually whitest at low elevations, frequently appears yellow or brownish in exposed sites at high altitudes. The color differences are not entirely matters of site and exposure, however, as in some places distinctly white-barked and yellow-barked races of aspen are found adjoining one another with a clear line of demarcation between them. This line can frequently be traced for long distances, particularly in the spring, since the yellow-barked race puts out leaves earlier than does the white. Leaves on yellow-barked trees may be about the size and shape of spade pipes on playing cards when the buds on the white-barked trees first show green. The white-barked trees usually appear straighter and taller than the yellow ones on the same site (*3*).

ROOT SYSTEM

The root system of aspen is of particular interest, on account of the dependence of the species upon root suckers for reproduction.

The typical root system of aspen consists of numerous shallow roots radiating from the base of the stump, one or two of which, particularly in small trees, are distinctly larger than the rest and are the original roots upon which the tree formed as a sucker. The root-spread as a rule is downward and outward to a depth not greater than 2 feet, and from this lowest point the roots pursue an undulating course, rising to the surface of the ground and sinking again by turns. The ultimate feeding roots are found in all levels down to 2 or 3 feet, although most frequently from 6 inches to 2 feet.

Sprouts appear where the roots rise close to the surface, especially where two very shallow roots cross and the upper is brought very near the top of the soil. Certain small roots appear to be devoted primarly to reproduction, since they run for long distances in the shallower soil layers without much change in diameter or furcation, and with practically no feeding rootlets. When a sprout grows on such a root, a rapid thickening takes place near the point of attachment of the sucker and many feeding rootlets develop, particularly on that part of the root away from the parent tree. These usually remain functional for a long distance from the living tree, but rot off when the parent tree dies. Sprouts frequently are found near aspen stumps, but generally these come from roots of distant trees brought near the surface in crossing the large stump roots. These reproductive roots have been found also in old decayed stumps of conifers which they have penetrated, working up close to the top surface and turning sharply back down through the stump into the soil again. At the top point where the root makes a loop, a sprout or group is sent out through the top of the stump. (Figs. 2 and 3.)

CLIMATIC REQUIREMENTS

Aspen is a tree capable of growing in a wide variety of sites in a cool climate, particularly one characterized by long winters and short growing seasons. It is a trans-continental species through Canada, extending almost to the Arctic Ocean. In the Rocky Mountain region it is found in the altitudinal zones characterized by Douglas fir and Engelmann spruce. At its upper limit it usually fails to reach such extreme altitudes close to the climatic timber line as are occupied by limber pine (*Pinus flexilis*), bristle-cone pine, (*P. aristata*), white bark pine (*P. albicaulis*), or even alpine fir (*Abies lasiocarpa*). It is, however, found in favorable sites only a few hundred feet lower, and may reach very good development in the higher parts of the spruce-fir type. The absolute altitude reached naturally varies with latitude. In the San Francisco Mountains of Arizona aspen reaches an altitude of 9,500 feet, in Colorado as high

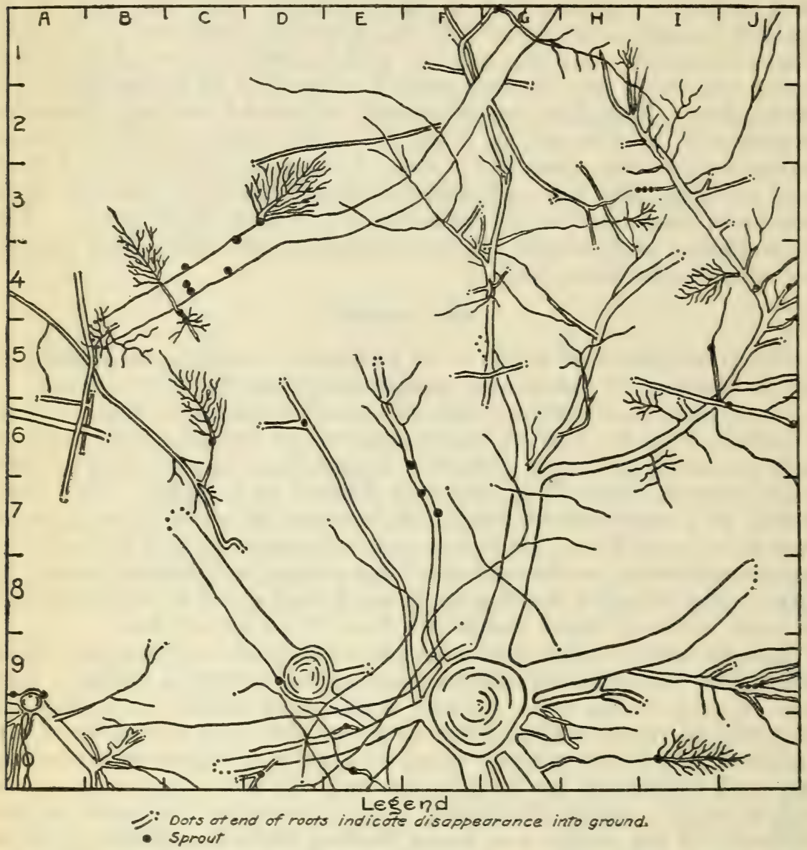
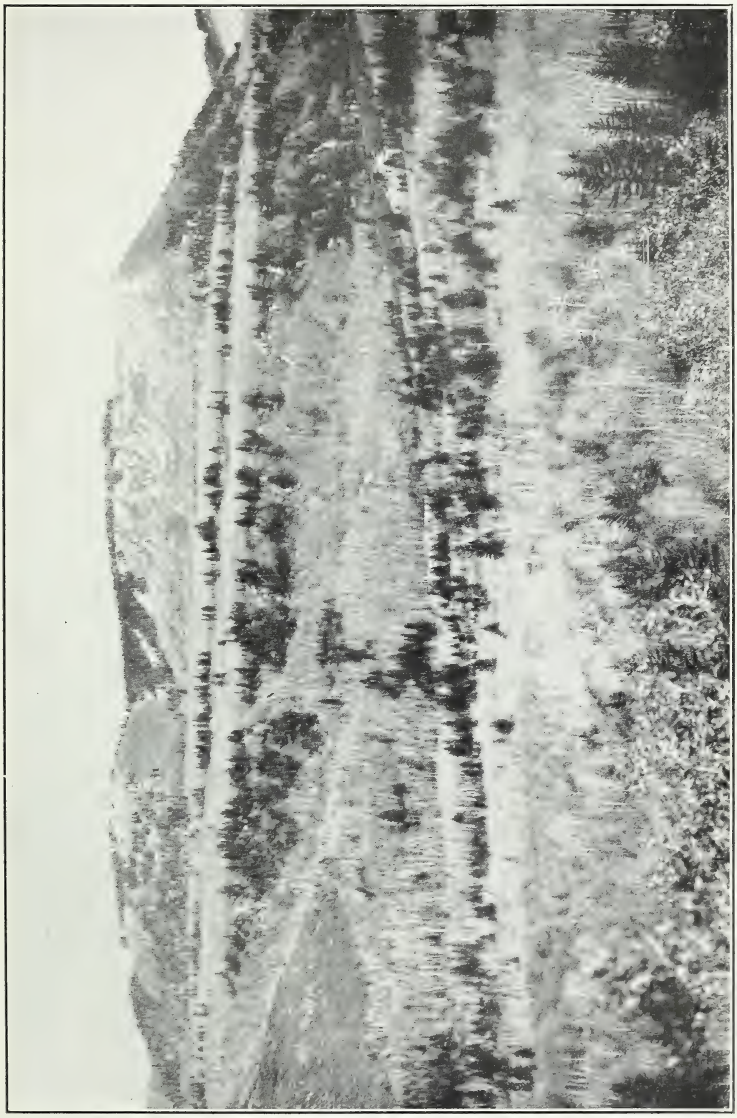


FIG. 2.—*Aspen root systems excavated to the depth of 1 foot.*—Reference is made to different areas on this figure by means of Nos. 1 to 10 along the left edge and the letters A to J along the top. The area referred to may be located by running horizontally from the number given and perpendicularly from the letter and noting where they cross. For example, the large stump near the bottom of the figure lies in F–10 and G–10. Roots from which trees in the old cut-over stand originated as sprouts are shown in A–9 and from 7–C to 9–D. These roots are much larger than any others on these trees. Rootlets apparently devoted primarily to reproduction, being free from feeding rootlets, run from D–10 to E–7 and from F–7 to H–9. When sprouts occur on such roots rapid thickening takes place and many feeding rootlets are sent out as in C–6, I–10, and B, C–4, 5. On larger roots this does not happen, as in F–7 and I–9. Root collar suckers are not frequent, but appear at A–9 and D–9



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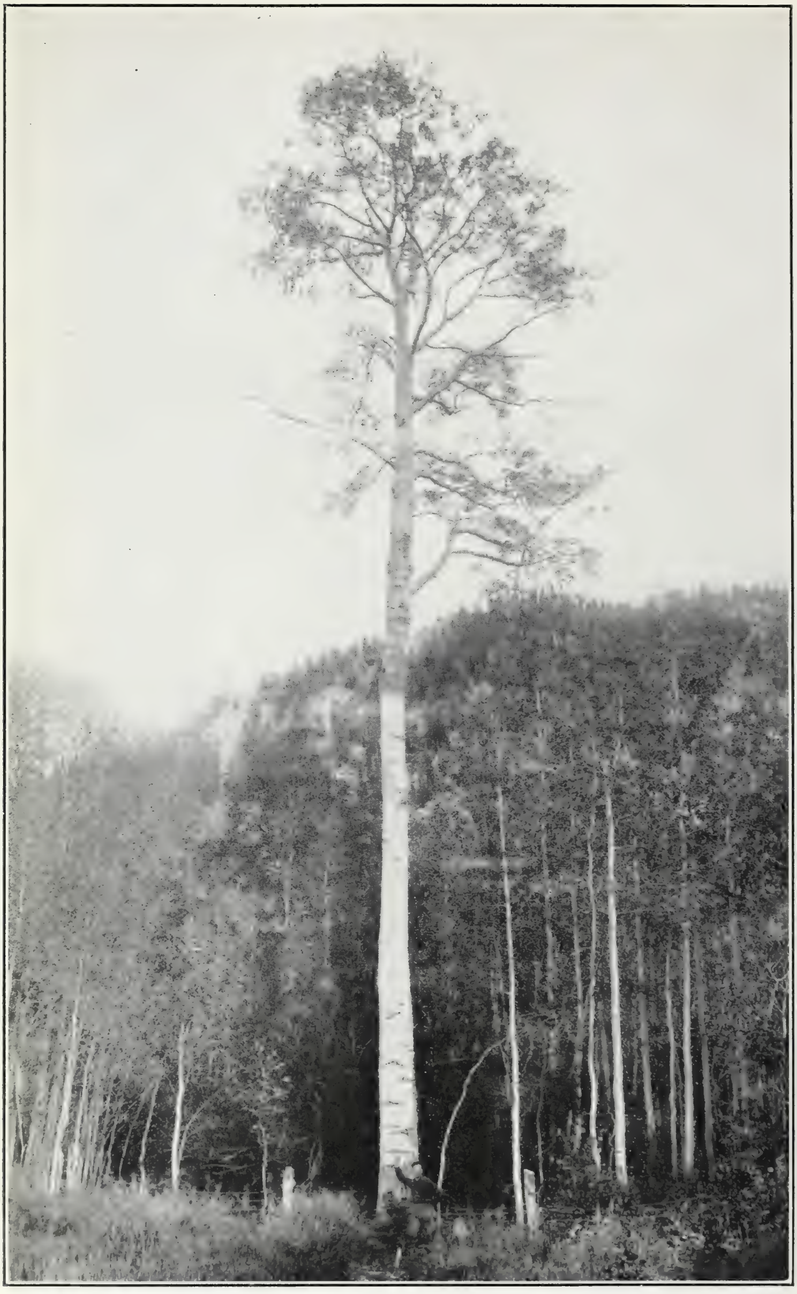
CHARACTER OF ASPEN STAND IN CENTRAL UTAH

Ephraim Canyon, Manti National Forest, where most of the intensive studies on aspen mentioned in this bulletin have been made



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AVERAGE MAXIMUM SIZE OF ASPEN. MANTI NATIONAL FOREST, UTAH

F-152822

ASPEN ON SITE QUALITY I, 110 YEARS OLD, 80 FEET TALL

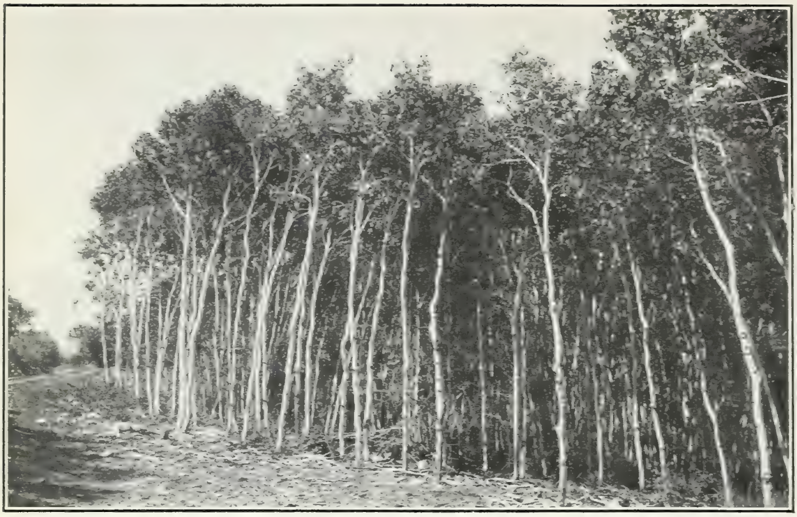

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FIG. 1.—ASPEN ON SITE QUALITY 3, AT THE LOWER LIMIT OF THE TYPE WHERE IT BREAKS INTO AN OAK BRUSH-SAGEBRUSH MIXTURE

About 50 years old and 30 feet tall

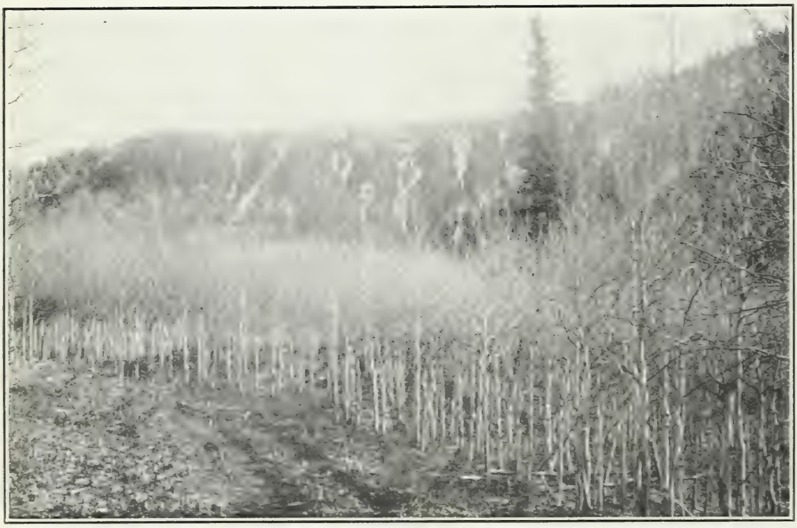

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FIG. 2.—ASPEN ON SITE QUALITY 5, ON A THIN ROCKY SOIL

The stand is 40 years old and about 20 feet tall as 12,000 feet (Engelmann spruce timber line), in central Utah to extreme ranges of 10,500 feet, while in Idaho (Targhee National Forest region) it is seldom found above 7,500 feet. At these extreme altitudes snow may lie on the ground from the latter part of September until the middle of June, and drifts are known to last well into August, so that the extension of the aspen may be limited by large snowdrifts where the local topography favors their formation. On south slopes at high elevations aspen becomes brushy, bent and twisted by heavy snows, or is confined at such elevations to moist areas only.

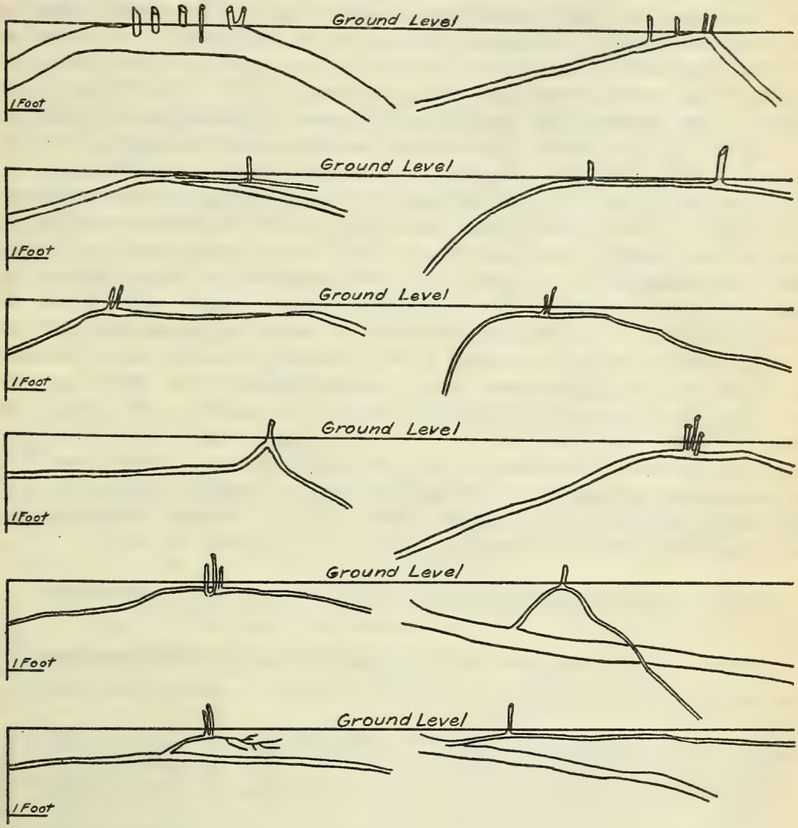

FIG. 3.—Development of aspen root suckers. This shows how shallow suckering roots lie and how the suckers tend to develop closely around the highest point on the root

The lower limits of the aspen type are found along streams far below the range of the extensive stands. In the western yellow pine type considerable areas of poorly developed aspen are common on north slopes and in moist swales, although the region may be devoid of permanent watercourses. Rarely, except in the Nevada region, do they enter the piñon-juniper type even along streams. In central Utah, where the western yellow pine type is lacking, aspen runs down to join the chaparral (oak and sagebrush types) at an elevation that varies widely with slope and exposure; also in the lodgepole pine region aspen commonly extends through the tension zone at the lower limit of the lodgepole type, thence in sheltered localities and along streams out into the sagebrush type for considerable distances. In Arizona, Utah, and Colorado, the lower limit is about 7,000 feet; in Idaho and Wyoming, 6,000 feet.

The upper limit has a mean annual temperature around 35° F., about equivalent to southern Manitoba, and the lower limit 45° F., comparable with southern New England. However, the temperature extremes are very much less in the Rocky Mountains than in the mid-continent. Winter minima are not frequently much below −10° F. for more than a few days at a time at the upper limits of aspen, while summer maxima rarely exceed 85° F. The upper limit seems to be marked by insufficient summer growing temperatures.

Rainfall in the aspen type shows considerable variation. In the central Rocky Mountain region of extensive aspen stands, this climatic factor is of first importance in limiting the lower extension of the type. In other regions where aspen occurs more sporadically, it is so frequently found on sites which have exceptional soil moisture that rainfall is a secondary consideration in determining the extent of the species. On the other hand, aspen will grow on average sites in Utah where there are no water supplies except from rainfall and where the annual precipitation is as low as 17 inches, of which only a little more than 5 inches falls in the growing season. In the spruce-fir type there may be as much as 30 inches per year. Where precipitation is low the stands reach poor development and become decadent at an early age, although even here they are decidedly superior to the thicket type of aspen, found at high elevations, which is little more than brush. Stands intermingling with sagebrush at low elevations are of site quality 3 and 4.[5]

TABLE 3.—*Mean temperatures in the aspen zone, in degrees Fahrenheit*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Colorado:													
Cheeseman	30. 7	29. 3	36. 8	43. 7	50. 9	60. 9	65. 5	68. 6	58. 2	47. 8	40. 1	29. 7	46. 8
Estes Park	22. 7	25. 9	31. 9	36. 6	44. 4	55. 7	62. 1	60. 6	52. 4	40. 8	33. 2	30. 2	41. 4
Fremont	25. 7	23. 7	29. 5	33. 7	42. 9	52. 9	57. 6	56. 0	49. 9	39. 9	33. 6	24. 9	39. 2
Lake Moraine	16. 6	19. 2	28. 9	38. 4	45. 6	55. 1	60. 1	59. 0	52. 2	41. 6	30. 8	15. 3	38. 6
Silverton	16. 3	17. 7	23. 0	31. 6	42. 8	47. 8	54. 6	52. 8	45. 7	36. 8	27. 1	15. 9	34. 3
Telluride	20. 8	22. 9	27. 8	36. 5	44. 0	53. 1	57. 8	55. 9	50. 6	40. 2	31. 0	21. 2	38. 5
Wagon Wheel	15. 7	17. 8	25. 0	33. 6	42. 4	51. 8	55. 9	54. 2	47. 5	32. 4	25. 9	15. 3	34. 8
Idaho: Irwin	20. 2	21. 7	31. 3	41. 0	49. 5	56. 8	64. 3	62. 3	53. 3	43. 0	32. 1	19. 9	41. 3
Utah:													
East Portal, Strawberry Tunnel	11. 4	14. 6	21. 9	31. 5	41. 9	50. 7	57. 1	54. 6	47. 4	39. 4	27. 2	15. 1	34. 4
Soldier Summit	17. 7	21. 8	28. 4	39. 5	46. 6	53. 5	60. 5	60. 8	51. 1	41. 2	29. 0	17. 5	39. 0
Winter Quarters	16. 5	18. 2	25. 3	35. 7	43. 4	51. 3	58. 2	56. 7	47. 9	36. 5	26. 8	15. 5	36. 0
Wyoming:													
Afton	17. 1	18. 9	27. 5	38. 2	46. 9	55. 7	61. 1	59. 9	52. 7	42. 0	29. 7	17. 4	38. 9
Alta	17. 2	18. 0	24. 7	37. 0	45. 3	53. 4	59. 1	57. 6	50. 1	41. 1	28. 9	17. 2	37. 5

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[5] See Table 6, p. 13, for criterion of sites.

TABLE 4.—*Rainfall in the aspen zone in inches*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Colorado:													
Cheeseman	0.21	0.64	0.80	1.85	1.89	1.58	3.34	2.37	1.56	1.05	0.51	0.78	16.58
Estes Park	.56	.74	1.20	2.30	2.84	1.19	3.28	1.69	1.74	1.53	.96	.56	18.59
Fremont	.50	.84	1.12	2.96	1.98	2.95	3.87	3.27	1.45	1.11	.42	.99	21.46
Lake Moraine	.79	.98	1.78	3.29	2.72	2.43	4.49	3.58	1.49	1.72	.76	.85	24.88
Silverton	3.13	2.11	2.68	1.61	.96	1.47	2.96	3.20	3.00	3.12	1.33	2.15	27.72
Telluride	2.11	1.55	1.93	2.48	2.52	1.09	2.84	2.77	1.40	2.02	1.48	.86	23.05
Wagon Wheel Gap	1.22	1.17	1.37	1.55	1.04	1.26	3.51	2.10	1.63	1.77	1.32	1.28	19.22
Idaho: Irwin	1.35	1.00	1.24	1.25	2.10	1.40	1.00	.92	1.26	1.52	1.09	1.18	15.31
Utah:													
East Portal, Strawberry Tunnel	2.47	2.25	2.46	1.53	1.39	1.02	1.72	1.20	1.92	2.45	1.37	1.59	21.37
Huntsville	2.98	2.53	2.54	1.69	2.12	.72	.62	.87	1.04	1.70	2.03	1.88	20.72
Soldier Summit	1.29	1.68	1.70	.68	.86	.26	.64	.79	1.01	.64	1.15	1.51	12.21
West Portal, Strawberry Tunnel	4.13	3.59	2.42	1.83	1.44	1.36	1.71	1.56	2.68	1.93	2.68	2.70	28.03
Winter Quarters	2.96	1.85	1.41	1.69	1.40	1.29	1.90	2.05	1.67	1.67	1.35	1.39	20.63
Marion	2.28	1.81	2.66	1.72	2.21	1.06	.74	1.63	1.54	1.26	1.61	1.75	20.27
Wyoming:													
Afton	1.41	1.49	1.74	1.39	2.43	1.43	1.05	1.08	1.41	1.40	.76	1.28	16.87
Alta	2.10	1.40	1.27	1.70	2.66	2.19	1.42	1.02	1.80	1.90	1.70	1.50	20.66

TABLE 5.—*Location of meteorological stations in the aspen type*

Station	Elevation	Location
Colorado:	*Feet*	
Cheeseman	6,890	Near lower limits of aspen type.
Estes Park Fish Hatchery	8,000	Near the aspen type.
Fremont Experiment Station	8,850	Located in potential aspen type, small patches within short distance of station.
Lake Moraine	10,265	In spruce-fir type where aspen of poor quality occupies burned-over areas.
Silverton	9,400	Near the aspen type.
Telluride	8,756	Located in aspen type.
Wagon Wheel Gap	9,610	Located in aspen type.
Idaho: Irwin	5,200	Nearly at the elevation of the lower edge of the aspen type; poor quality.
Utah:		
Great Basin Experiment Station.	8,700	Located in a clearing in the middle of the aspen type. Site quality 2.
Huntsville	5,100	Aspen descends to elevations approximately equal to Huntsville on north slopes near town. It is of very poor development.
Marion	6,400	Aspen extends down streams almost to the elevation of Marion, and is found on a north slope at Peoa a few miles north at about the same elevation; quality poor.
Soldier Summit	7,454	In brush type. Aspen of poor quality extends down draws to elevations much lower than this station, and generally covers north slopes near by.
Strawberry Tunnel—		
East Portal	7,606	In the aspen type.
West Portal	7,650	
Winter Quarters	7,625	Virtually in the aspen type, of varying quality on different slopes and exposures, average is good.
Wyoming:		
Afton	6,250	The aspen type descends to the level of the station and lower in nearby mountains.
Alta	6,500	In the lower aspen type of about site quality 3 to 4.

A number of cooperative observers' stations of the United States Weather Bureau are located either in the aspen type or near its edge in Colorado, Idaho, and Utah. Meteorological records from several of the most typical stations as given above are shown in Tables 3 and 4, and indicate the type of climate in which aspen grows in the central Rocky Mountain region.

SOIL AND MOISTURE REQUIREMENTS

Aspen grows in practically every variety of soil found in the climatic belt to which it is suited, from loamy sands in parts of the western yellow-pine type to heavy clays characteristic of parts of central Utah; but the development of stands varies considerably on different soils. The chief direct influencing factor is rockiness of the soil, which by hindering the lateral spread of the shallow roots and interfering with the tendency to rise close to the surface, restricts the reproductive ability of the tree and its development. Soil has also an indirect effect on the development of the aspen type through its influence on conifers, for any factors which assist the growth and regeneration of conifers tend to reduce aspen through suppression. Rocky areas, therefore, have both a direct and indirect effect, as they are favorable to conifers. The best aspen development is on rich, deep-soiled flats supplied with plentiful moisture. Heavy-soiled flats are most difficult for conifer reproduction. There is evidence to show that on such sites recurrent surface fires have spread with exceptional ease in the uninterrupted stretches of dry grasses and herbaceous débris accumulated under aspen shade, destroying rival growth; and for this indirect reason large flats or rolling country tend to bear the largest pure aspen stands at present. But even here, without the aid of fire, conifers would probably have replaced aspen as a type.

Aspen is apparently a little less drought resistant than either Douglas fir or white fir (*Abies concolor*), which are very slowly extending into altitudes below the aspen. Aspen demands more moisture than western yellow pine, and the conifers of the piñon-juniper type, but appears to be more resistant than Engelmann spruce and alpine fir in the spruce-fir type, although probably not more so than limber pine, which is frequently found in this type. In the lodgepole pine region it seems hardier in this respect than the pine, for it usually runs out into the sagebrush more actively. The advantage which aspen has in occupying drier sites is not, however, so much a matter of actual water requirements of the full-grown trees as of the difference in the method of reproduction.

The critical period with conifers is during germination and the seedling stage of life, a period through which aspen does not have to pass. Even though it was originally established on a moist site which has become drier on the surface, and in spite of retrogressive successions due to fire, heavy grazing, or erosive agencies, if not to actual climatic changes, aspen can hold its own as long as moisture in the deeper soil layers does not fail. However, conifers once established would probably form types on every aspen site, not excepting those on south and west slopes at high altitudes into which conifers are at the present time coming only sparingly or not at all. In fact, conifers develop into large trees, nearly as large as on the best sites, in places where aspen is scarcely more than a shrub.

QUALITY SITES

Owing to the extreme variability in the development and growth of aspen under different soil and climatic conditions, it is necessary to consider every phase of silviculture and management in connection with site quality. Therefore a classification of sites is necessary before a presentation of data regarding the tree is undertaken.

Height growth has been adopted as the criterion of site quality in this bulletin. Results shown under growth, yield, etc., are identical, however, whether height or annual volume increment is chosen as the criterion of site, as there is extremely close correlation between the two.

Five site qualities have been recognized, based upon the height of the dominant trees in the stand and the age of the stand. The dominant rather than the average height was chosen as the basis because otherwise a determination both of the age of the stand and of the average diameter would be required. Table 6 gives the age-height relations on each site.

TABLE 6.—*Criterion of site quality—Aspen*

Age	Height of dominant trees				Age	Height of dominant trees			
	Site 1	Site 2	Site 3	Site 4		Site 1	Site 2	Site 3	Site 4
	Feet	*Feet*	*Feet*	*Feet*		*Feet*	*Feet*	*Feet*	*Feet*
10 years	13	11	8	6	90 years	80	71	60	47
20 years	25	19	15	13	100 years	81	74	63	49
30 years	37	29	23	19	110 years	82	75	66	--------
40 years	47	38	30	24	120 years	83	76	--------	--------
50 years	57	48	37	30	130 years	83	--------	--------	--------
60 years	66	55	44	35	140 years	83	--------	--------	--------
70 years	73	62	50	40	150 years	83	--------	--------	--------
80 years	77	67	55	44					

Trees less than 40 feet tall at maturity belong to the unmerchantable-thicket type of aspen of site quality 5.

In general, site quality 1 is found on moist flats having deep, perhaps rather heavy, soil. The trees reach good size, and are clean-boled and straight. (Pl. III.)

Site quality 2 includes the great bulk of the stands of good quality in the central Utah region. In general, these sites are relatively not so well watered and are more likely to be on slopes, as compared with site quality 1. The trees reach saw-log size before decay renders them valueless.

Site quality 3 includes situations similar to quality 2 as to topography, but usually at elevations below the best altitudinal zone for aspen. It also occupies steep slopes within the optimum zone. (Pl. IV, fig. 1.)

Site quality 4 is found nearly everywhere at the lower limits of aspen, and also on south slopes at higher elevations. It usually bears a dense pole stand which rarely develops trees of saw-log size.

Site quality 5 includes great areas of aspen on south and west slopes, on poor soils, and particularly at elevations above the zone of best development of the species. (Pl. IV, fig. 2.)

These site classifications can not be directly translated into terms of site classifications for coniferous trees, as there is a great difference in the habit of growth of conifers and aspen, and they do not respond to changes in their environment in the same ways. A further discussion of aspen and conifer sites will be found under "Yield."

TOLERANCE

Aspen is an exceedingly intolerant tree, being less able to stand shade than any of the coniferous species associated with it, with the possible exception of limber pine. Sprouting goes on with little success in most stands until they begin to open from old age. An analysis of light intensities (Table 7) shows that even where the light is as bright as half the normal full sunlight sprouting is unsuccessful compared to what it is in clearcut plots in full sunlight.

TABLE 7.—*Relation of intensity of light to number of sprouts per acre*

Light intensity [1] (full sunlight 1.00)	Number sprouts per acre	Light intensity [1] (full sunlight 1.00)	Number sprouts per acre
1 0	40,000	0.3 to 0.4	2,436
0.5 to 0.6	2,784	0.2 to 0.3	1,255
0.4 to 0.5	2,175	Less than 0.2	Usually none.

[1] Measured with the Clements photometer.

Taking a specific example for illustration, it was found that the intensity of light under a stand where sprouting has for years shown itself to be only partly successful was approximately one-fourth full sunlight. Sprouts from this plot compared with those from the open near by very strikingly show the difference in sprout development beneath a parent stand and in one where clear cutting has taken place. Although the sites are the same except for the degree of light, 3-year-old sprouts average only 8.7 inches tall under the old stand, whereas in the open they are 42.3 inches tall and very much more vigorous in appearance. Under very dense aspen stands the light intensities may be as low as 0.07 normal; but, even in such places, an intolerant species like western yellow pine will remain alive, although growing very spindly, while Douglas fir, white fir, alpine fir, and Engelmann spruce will grow fairly readily. Aspen sprouts do not develop sufficiently to be generally apparent where light intensities are under 0.2 normal. Conifers can therefore readily suppress aspen, as intensities as low as 0.03 to 0.06 are found in average spruce stands, and even in lodgepole pine 0.07 to 0.08 is normal (*5*) Pearson's results in Arizona (*10*) indicate the following intensities of light as favorable to good growth of conifers: Western yellow pine 0.41 to 0.57; white fir 0.027 to 0.068; Douglas fir 0.133 to 0.192; Englemann spruce 0.033 to 0.060.

Since the usual light intensity in aspen stands of moderate density is about 0.2, it is evident that they offer excellent opportunities for satisfactory regeneration of conifers.

SUSCEPTIBILITY TO INJURIOUS FACTORS

Aspen is a tree which is extremely susceptible to attacks of fungi and is also considerably injured by many other biotic and climatic agencies. Fungi (rots) and grazing damage, however, are practically the only ones which have a great bearing on management.

FUNGI

Fomes igniarius (heart rot) and *F. applanatus* (butt rot) are found attacking aspen throughout its entire range. The wood of aspen is not durable, and the pathological aspects of management, therefore, assume considerable importance. Studies made by Meinecke[6] on aspen in central Utah, on the better class of sites (1 and 2) show that trees as young as 35 years may become infected with decay. Up to an age of 80 to 90 years, however, decay is negligible, and is generally connected with injury, usually fire scars. From 80 or 90 years of age and older decay becomes important, and beyond 100 years ("critical age") decay causes serious loss. Above 110 years ("age of decline") thrifty trees are likely to be seriously decayed. The gross cull due to decay in standing timber of different ages on sites 1 and 2 in central Utah is shown in Table 8, from which it appears that the pathological rotation should be placed at about 110 years. As is shown later this is as long as is needed silviculturally.

TABLE 8.—*Gross cull in aspen due to decay and other causes*[1]

Age class	Decay (per cent of merchantable volume)	Other[2] (per cent of merchantable volume)	Total (per cent of merchantable volume)
30 to 40 years	1.4	0.1	1.5
41 to 50 years	----------	----------	----------
51 to 60 years	4.7	1.4	6.1
61 to 70 years	5.9	8.3	14.2
71 to 80 years	5.6	.2	5.8
81 to 90 years	3.0	6.7	9.7
91 to 100 years	11.5	1.1	12.6
101 to 110 years	18.1	.4	18.5
111 to 120 years	26.5	1.0	27.5
121 to 130 years	41.5	3.2	44.7
131 to 140 years	10.3	11.2	21.5
141 to 168 years	22.5	1.9	24.4

[1] Adapted from Table 1 in the report by Meinecke cited above.
[2] Includes canker, fire scars, frost cracks, and incidental wounds.

On poorer sites decay starts in at a much earlier age and sometimes may render a stand valueless before it attains an age of 40 years. The effects of decay are not uniform, however, and certain regions where the site seems favorable and the trees grow to large sizes are nevertheless notorious for rotten trees. Undoubtedly much of this apparent difference in amount of decay in different regions is due to the frequency of fires, as basal fire scars are the chief avenues of entrance of decay according to the studies made by Meinecke, which show 76 per cent of small fire scars infected, 88 per cent of medium-sized scars, and 108 per cent of large scars (more than one infection per scar). In two-storied stands, the overwood is usually badly decayed due to infections through basal fire scars, resulting from the fire which gave rise to the underwood. In average stands where it is possible, rotations should not be longer than 80 years, in order to minimize the loss by decay.

In young trees an unusual number of persistent dead branches up and down the trunk indicates a decayed heartwood, while in older trees swelled butts and an unusually early production of dark, furrowed bark are unmistakable evidences of decay. Vigorous, sound trees are characterized by a smooth, light-greenish bark all over the trunk, even the old branch scars. An unhealthy tree has a bumpy bark, and old branch scars are black and large. The larger these black scars are the more likely the tree is to be decayed. Fire scars ("cat-faces") are, of course, almost certain indicators of decay.

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[6] Meinecke, E. P. Pathology of Quaking Aspen in Relation to the Management of the Species in District 4. MS. report.

Aspen canker is a disease the causal organism of which is unknown. It is found plentifully in localized areas through the region covered by this study. It does not appear to spread very easily, and the infected areas are usually small—an acre or less. In these areas, however, practically every tree may be badly infected. Bad attacks of this disease make the wood unfit for any use but round timbers. In the absence of knowledge of the cause of the canker or the life history of the organism, no special treatment can be recommended. Canker-infected cutting areas should be clean-cut, whether merchantable or not, and the débris burned, in order to eliminate this disease, if possible, from future stands.

Another canker disease which is frequently fatal to trees in dry, exposed situations, and sometimes to larger thrifty specimens in favorable sites is caused by *Cytospora chrysosperma*. The disease is not common in Utah, and is more an enemy of the planted species of poplar in the valleys than of the wild aspen (*8*). Occasionally, however, it has occurred in other places within the range of aspen to such an extent that entire stands have been destroyed.

A powdery mildew, *Uncinula salicis*, the mycelium of which forms white powdery areas on both sides of the leaves, is found throughout the range of aspen in the Rocky Mountain region. No great damage is done by this fungus except in dense stands of sprouts where the most serious injury has been observed.

In Colorado extensive damage has been caused in certain localities by a leaf fungus, *Sclerotium bifrons*, which defoliates the trees. The fungus is only slightly known and special remedial measures can not be given now.

The conifers associated with aspen are very much less disposed to diseases caused by fungi, and there is no difficulty in growing any of them to saw-log size in a sound condition.

INSECTS

Insects attack both the leaves and trunks of aspen to some extent in the Rocky Mountains, but rarely do great damage. The most noticeable insect ravages are caused by defoliation by adult Curculionid beetles (*Thricolepis inornata*) and by the larva of some Chrysomelid beetles which are very plentiful in local regions in certain years and take practically every vestige of foliage from the trees. This is not usual, however, and since repetitions do not seem to occur at very frequent intervals in the same stand, the damage is limited to the reduction of the year's growth.

A cerambycid borer (*Saperda calcarata*) is very destructive to aspen in its northern Rocky Mountain range and in Colorado. The larva, which is nearly 2 inches long when fully grown, bores under the bark and through the wood, weakening the trees or causing their death. Hofer describes in detail the aspen borer and also lists and describes briefly other minor insect enemies (*6*).

One of the cecidomyid group of gall insects also does considerable damage to aspen buds in April and May, stunting the trees but not killing them.

One of the plant lice, *Chaitophorus sp.*, does some damage by killing back tender shoots, although the trees are not seriously hurt.

In Montana a number of insects infesting broad-leafed trees include aspen in their attacks, but they do not often damage the aspen severely. Among these are *Lina scripta*, a chrysomelid beetle similar to the elm leaf beetle; *Onychagrotes rileyana*, a noctuid moth larva, which works in the green bark; larva of *Euvanessa antiopa* and *Aglais j-album;* and the buprestid beetles *Chrysobothris femorata* and *Agrilus anxius*. These are doubtless found in regions south of Montana as well.

In Colorado severe local attacks by a tent caterpillar, *Malacasoma fragilis*, have been noted, but appearances give the impression that natural enemies usually hold this menace in check.

The investigations of the Bureau of Entomology throughout the Rocky Mountain region have indicated that the aspen borer (*Saperda calcarata*) and *Agrilus anxius* are among the most important insects attacking the aspen.

A common ambrosia beetle, *Trypodendron* (*Xyloterus*) *retusum*, which has been noted especially on the Cache Forest in Utah, attacks the wood of weakened and dying aspen trees.

MAMMALS

Mammals are the chief living enemies of aspen. Sheep are by far the worst, followed by cattle, and wild rodents such as rabbits, mice, and gophers.

Sheep grazing is very frequently destructive to aspen sprouts to such an extent that, if continued longer than a rotation of aspen, it means the extinction of the type in many localities. This phase of aspen management has been covered thoroughly by Sampson (*12*), and his findings appear to apply to all the Rocky Mountain region. The most important result of these studies was the discovery that sheep grazing is especially destructive on clean-cut areas, and that if it is continued three consecutive years all aspen sprouts will be absolutely killed out. Sheep do not reach higher than about 42 inches, however, and protection for a long enough period to allow a certain minimum number of the sprouts to pass this height is all that is necessary. This will vary with the rate of height growth and the number of sprouts per acre.

Cattle grazing is less uniform and the damage depends more upon the intensity of grazing and the nature of the forage on the area. In some places damage is negligible and in others it is very severe. The degree of protection will necessarily vary with grazing conditions, and, where these are very bad, complete protection may be needed until the aspen sprouts are entirely safe from destruction by browsing, or until the sprouts are 55 to 60 inches tall.

Sampson's publication presents practically all data available along this line. Table 9 has been prepared to show the percentage of sprouts in various height classes as an aid in determining the period of protection necessary to insure satisfactory regeneration in different sites, 2,500 sprouts per acre at the end of the third year being considered satisfactory density.

TABLE 9.—*Percentages of sprouts safe from destruction by sheep and cattle grazing at the end of first to fifth years*

Height class	Percentage of total sprouts in each height class at end of year specified				
	First	Second	Third	Fourth	Fifth
1 to 40 inches, not safe from sheep or cattle	100	79	50	33	20
Over 40 inches, safe from sheep	0	21	50	67	80
40 to 60 inches, safe from sheep, not from cattle	0	18	38	46	36
Over 60 inches, safe from sheep and cattle	0	3	12	21	44

Gophers are sometimes responsible for the destruction of many sprouts and superficial roots, and on areas where they are extremely numerous regeneration may be decidedly unsatisfactory. Such situations are not frequent, and are of slight practical importance.

Mice, rabbits, and gophers sometimes indulge in wholesale girdling in sprout stands and cause entire destruction of trees over limited areas, much of this work being done in winter under the snow.

On the whole, aspen suffers very much less from damage by rodents than do the conifers associated with it, although the conifers are much more resistant to other forms of animal damage. Sheep grazing, the worst enemy of aspen, can be readily controlled, but the rodent damage to conifers can not be generally limited at the present time. Most of the damage is done by snowshoe rabbits which eat off the conifer terminals repeatedly as long as the tree top remains below the level of the deepest snow of the winter, which is 3 to 8 feet in most of the aspen zone. Trees are rarely killed outright by this damage, but height growth is greatly retarded, the trees developing into flat, spreading bushes, unable to reach a height of 60 inches (the top of the snow) for possibly as long as 30 years. Very frequently several laterals succeed in getting above the maximum snow level simultaneously, forming a misshapen tree with several trunks. As a tree so attacked increases in diameter the injury becomes less visible, but when the butt logs from such trees are sawed the lumber at the lower end is of very poor quality, full of pin knots and large loose knots from old dead leader stubs.

No species of conifer is immune from these attacks, although the degree of damage varies widely with location and species; and there is a certain degree of safety in numbers, conifers thinly scattered through the aspen being the most seriously attacked. Where groups of mature conifers are extending their borders into the surrounding aspen with multitudes of seedlings, the reproduction suffers much less. Of the important conifers, Douglas fir is usually eaten and damaged most severely, with white fir next. Alpine fir is badly attacked in the Wasatch National Forest, but practically not at all in the neighborhood of the Great Basin Experiment Station. Engelmann spruce is not an active invader of aspen sites, and isolated seedlings are rare, so that its relative immunity may be due as much to this fact as to any possible unpalatability. Blue spruce, which is stronger-flavored and has stiffer, sharper leaves, is frequently eaten. The blue spruce grows much more scatteringly than Engelmann spruce, and at a lower elevation, where coniferous food is scarcer.

In regions where rabbit damage is severe, the reduction of height growth, as shown in Table 10, materially increases the necessary rotation of conifers and reduces the value of the product, thus handicapping conifers in relation to aspen in forest management in many places (*4*).

TABLE 10.—*Effect of snowshoe rabbit injury on height growth of conifers*

Age	Height					
	Douglas fir		White fir		Alpine fir	
	Normal	Injured	Normal	Injured	Normal	Injured
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
10 years	0.6	0.6	0.6	0.6	0.6	0.6
20 years	1.9	1.4	1.8	1.8	1.8	1.6
30 years	5.1	2.5	3.8	3.0	4.0	2.8
40 years	9.8	3.7	7.0	4.6	8.8	4.2
50 years	14.4	6.4	12.5	7.4	16.8	6.0
60 years	---	10.8	26.0	13.5	---	9.2
70 years	---	15.6	---	---	---	---

FIRE

Although evidences of past fires in aspen are plentiful, and extensive fires have run through the type within the memory of living men, they are extremely rare at the present time. The aspen leaf fall and débris is too scant to carry fire. Grazing has undoubtedly been chiefly responsible for reducing the fire hazard, as pockets in the aspen type inaccessible to livestock show rank undergrowth of tall, leafy grasses, such as *Bromus*, *Agropyron*, and *Stipa*, as well as herbs, which are usually very scarce in the portions of the type grazed with ordinary intensity. Other evidence points to the same conclusion, that fires stopped at about the same time that grazing became heavy in the mountains.

In connection with Meinecke's study of decay in aspen, it was found that in the stands in Ephraim Canyon, which are typical of central Utah, fire scars were plentiful. Owing to the difficulty of counting aspen rings with absolute accuracy, especially in partly decayed wood, it is improbable that fires occurred in every single year determined in this study. Nevertheless, the data indicate that there were fires in this locality in about 1770, 1800, 1816, 1825, 1835, 1841, 1849, 1857, 1864 or 1865, and 1867 (this was a very large fire of incendiary origin, remembered by the older settlers). Following this, frequent fires until as late as 1875 are indicated by the fire scars. In 1884 another large fire occurred. The study revealed only 4 trees showing fire scars after that date (compared to 43 in the period 1863 to 1873), 1 in each of the years 1889, 1894, 1897, 1904. These results indicate that small, light fires occurred at intervals of 7 to 10 years in the same general region previous to the settlement of the country. After the mountains were invaded by the logger and stockman, there was a period of frequent and large fires, after which fires became fewer and fewer, and now virtually none occur.

A very light fire will kill aspen, as the bark is thin and green, with no protecting corky layers; while basal scars, which lead to destructive heart rot, will be made on good-sized trees by the lightest of fires. In such surface fires, however, the temperatures in the ground never become very high and root suckering is not impaired. Conifers are, of course, more resistant to fire when past the sapling stage, but once destroyed they seed in slowly. A 50-year fire rotation would probably keep conifers entirely out of all the aspen type, except on north slopes or in moist localities favorable to the rapid development of the coniferous trees, although aspen would flourish under such conditions. But under present conditions, fire is not a factor to be reckoned with in forest management in the aspen zone.

CLIMATIC FACTORS

Injurious climatic factors are not of sufficient importance either to aspen or the associated conifers to affect management. Windfall in aspen is usually clearly due to excessive butt or root rot and is seldom extensive over large areas, being usually confined to single large trees or groups of trees. In conifers associated with aspen, windfall is occasionally widespread; but nowhere is it of enough importance to cause any modification of management in favor of aspen.

Frost frequently retards aspen seriously, particularly the tender sprouts. When late spring frosts occur, not only the leaves but also the twigs of the last year's growth may be frozen, and the second crop from older dormant buds may not become well developed until well into July.

These frosts, or more properly freezes, may occasionally be so severe that entire full-grown trees are killed outright. This occurred in many parts of Utah and southern Idaho, especially within the Engelmann spruce zone, during the freeze of May 31, 1919. Temperatures probably fell as low as 12° to 15° F. at this elevation, at a time when the buds were just bursting. In the Douglas fir zone, where the minimum temperatures probably ran from 17° to 20° F., injury was rare (*7*).

Early fall frosts have no bad effect except killing back sprouts that have developed tardily, since growth ceases and hardening of the tissues normally begins during the last week in July at middle elevations (8,500 feet) in Utah.

REPRODUCTION

As there is practically no production of seed by aspen, at least not in Utah, this method of reproduction is of no importance in the management of aspen stands in that State. Suckering from the roots is the method by which regeneration takes place. (Pl. V, fig. 1.) It is almost inconceivable that this was always the case, as the aspen could hardly have spread by sprouts alone so widely or into so many small, isolated areas, even in times of more favorable climatic conditions. Rocky outcrops, swamps, and alkali areas are effective barriers to root extension. It seems more probable that at the close of Pleistocene times aspen came in by seed, occupying an ecological place similar to that which it holds to-day in the forests of Canada, spreading throughout the conifer types. The same drying and warming of the climate which reduced Lake Bonneville to the present Salt Lake and melted the glaciers also made aspen reproduction by seed more and more difficult, particularly as June is the driest month of the year. The temperatures, however, were not unfavorable to the vegetative growth of the established trees. The progress of drying, furthermore, tended to hinder the reproduction of the conifers and to make them grow in open stands, thus helping to prevent the exclusion of aspen by suppression.

The form of present-day stands, as well as the charcoal in the soil, proves that fires were prevalent in the aspen type during the last few hundred years at least. The impression is very strong also that the fire agency, coupled with the dryness of the climate, has for a very long time restricted the conifers, while it has tended to encourage the persistence of aspen stands. Nothing but the destruction of all sprouts in three successive years, or suppression by the close growth of conifers, appears to be able to displace aspen from areas it now occupies. On the other hand, it is now unable to invade areas made favorable by fires or logging, from which it was once excluded, except through slow marginal extension by roots. (Pl. V, fig. 2.)

The existence of islands of aspen which are clearly more than holding their own in the surrounding areas of sagebrush or chaparral suggests very strongly that these are the last relics of an old timber type, wiped out by surface fires, in which the aspen existed only as a scattered tree here and there. The progressive drying of the climate also has played its part in the formation of aspen islands in other types, leaving them in places where subsoil moisture is plentiful but the surface practically as dry as that on surrounding sites. These islands are common in mountains of sedimentary origin, where long, horizontal patches of aspen on dry hillsides mark the presence of subterranean outcrops of water-bearing strata.

At the present time, natural stands under undisturbed conditions appear to advance very slowly into adjacent openings. (Pl. VI, fig. 1.) This may be due largely to the destruction of the scattered sprouts by grazing. In such stands, fires not severe enough to kill the trees have the effect of immediately extending the type boundaries, as the roots sprout vigorously to their fullest extent, making on the margin of the old stand a new belt of aspen type. As a rule, this is about 15 feet wide, although sometimes it may be as wide as 50 feet. This is a very slow advance, however, since the process can probably not be repeated with success more often than once in 20 years, and actually takes place very infrequently.

Sprouting occurs in aspen stands continually and even in virgin stands, but owing to the intolerance of the sprouts and the small amount of growth energy they have as long as the parent trees remain alive, they are weak and inconspicuous and rarely live longer than a few years. Such sprouts are rare in young stands, but increase from year to year; and as the parent stand breaks up they become very numerous, forming an understory, if light is sufficient.

A prominent even-aged understory may also occur where light ground fire has killed some of the parent trees, thus opening up the canopy, destroying practically all the advance reproduction, and stimulating a vigorous sprouting. (Pl. VI, fig. 2.) A typical case of this persistent unsuccessful sprouting in fully stocked stands was shown by a permanent sample plot in a practically virgin two-aged (110 and 45 years) stand of site quality 2 on the Manti National Forest.

The first year of observation, 55 sprouts were noted, either of that or previous years. In the following year there were 2 new sprouts, only 33 of the former sprouts remaining. Next year the original 55 sprouts had been reduced to 18, although 6 new ones had appeared. Four years from the first observation of this sprout growth only 11 remained of the first lot, 1 of the second lot, 5 of the third, while the last two years of growth had produced additional sprouts of which 18 still remained.

Nisbet (*9*) states that in England the European aspen (*Populus tremula*), which is silvically equivalent to ours, will send up suckers from roots that remain alive in the soil long after the parent trees are cut out and the stumps have rotted away. From the many uneven-aged stands which exist in the Rocky Mountains, pointing to repeated regeneration without the agency of fire, it is evident that sprouting can remain sufficiently active to regenerate the stand with normal density, even at the maximum ages reached by aspen. In forest management on a coppice system, however, the vigor of sprouting at different ages frequently assumes considerable importance. To determine the effect of age on sprouting, acre plots were located in 70-, 90-, and 110-year-old aspen stands. These showed conclusively that reproduction after cutting is vigorous at any rotation likely to be used in practical management, and sufficient to restock the area fully.

From approximately 1,000 trees on each age plot, more than 110,000 suckers were sent up by the 70-year growth, and more than 100,000 by the middle group. The trees 110 years of age, under somewhat less favorable conditions, sent up more than 50,000 suckers. In the fifth year of regeneration, these plots averaged 28,500, 36,000, and 13,000 shoots per acre, respectively. The 70-year plot showed the highest growth, attaining an average of 57.5 inches; the middle plot averaged 41.9 inches; and the oldest, 46.4 inches.

Root-sucker sprouts are the form most frequently found. An examination of 6,724 sprouts showed that 91 per cent were root suckers, 8 per cent were from the root collar, and 1 per cent from the stump. Although there is little difference in the vigor of these sprouts, suckers from small roots tend to be small and weak, and as a class, those from the large, firm roots of the root collar seem most vigorous. Sprouts on the stump, although usually vigorous in development, are frequently torn loose by the weight of heavy settling snow and killed. Occasionally the weight of root suckers will twist a small, shallow root which has no strong lateral anchoring roots so that sprouts become decumbent shrubs. This is particularly true on steep slopes, where the weight of snow is added to that of the sprouts.

Second only to the question of the age at which stands should be cut to get good sprout regeneration, is the question of the season of cutting, since it is well known that in coppice management summer cutting usually gives rise to sprouts which are killed back by frosts. Three plots were cut over at different seasons (spring, summer, and fall) to determine the effect in the case of aspen. The results showed that when the cutting takes place in the growing season aspen sprouting is delayed and is spread over two years. The most sprouts followed the spring cutting and the fewest the summer cutting, but the present number is practically the same on all three areas, doubtless representing full stocking for the site, the average being 16,500 sprouts per acre after seven years. (Table 11).

TABLE 11.—*Effect of season of cutting aspen on sprout reproduction*

Cut	Number of sprouts per acre at end of—							
	Year cut	1 year	2 years	3 years	4 years	5 years	6 years	7 years
Spring	27, 598	85, 456	40, 112	30, 084	24, 416	[1] 22, 000	19, 620	[1] 18, 000
Summer	----------	53, 628	44, 472	30, 956	23, 108	[1] 20, 000	16, 568	[1] 15, 000
Fall	----------	34, 000	34, 880	23, 980	21, 800	19, 600	[1] 18, 000	16, 586

Cut	Average height at end of—							
	Year cut	1 year	2 years	3 years	4 years	5 years	6 years	7 years
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Spring	4. 0	12. 5	31. 2	41. 2	55. 0	[1] 60. 5	63. 9	[1] 67. 0
Summer	----------	16. 0	33. 5	46. 6	56. 4	[1] 62. 0	64. 9	[1] 68. 0
Fall	----------	7. 5	23. 1	39. 1	43. 1	48. 8	[1] 53. 5	56. 3

[1] Interpolated from curves.

The slower height growth on the fall-cut plot is ascribed to its position, which exposes it to more frost damage than the other two. This factor was especially marked in reducing the growth in the seventh year. It is not believed that the season at which the parent trees are cut can affect height growth of the reproduction after the third year. Between the first and second year after cutting there was still some sprouting going on, although it failed to counterbalance the losses from death. On the spring-cut plot it amounted to 3,045 sprouts per acre and on the summer-cut plot 8,410 per acre. It can not be determined for the fall-cut plot on account of incomplete figures from the examination the first fall after cutting. After the second year new sprouts practically ceased to come in.

REPRODUCTION OF CONIFERS ASSOCIATED WITH ASPEN

The advisability of changing aspen stands over to conifer stands depends, in a measure, upon the possibility of getting an adequate reproduction of the conifers in a reasonable length of time. Compared to aspen, which springs up in one year after cutting to many times the minimum requirements for satisfactory stocking, the best that conifers can do must appear slight. Since, however, conifer stands will be managed on a selection system, and should contain considerable advance reproduction at the time of cutting, a slow, sustained regeneration may be satisfactory. A plot located in aspen adjoining a white fir stand shows a total of 4,246 conifer seedlings per acre which have come in within the 50-year period following the last fire. All age classes are represented, showing a sustained invasion of conifers. Their apportionment is as follows:

The 1–10 year class shows 1,716 trees per acre; the 11–20 year class, 1,360; the 21–30 year class, 796; the 31–40 year class, 176; and the 41–50 year class, 198 trees per acre.

This shows an establishment of about 200 trees per decade which will go into the final stand, a rate of regeneration which is satisfactory for a white fir–Douglas fir site. In the Engelmann spruce–alpine fir type, reproduction proceeds at a much more rapid rate than this, but this is more necessary, as this type is much more dense and a larger number of stems per acre will be carried through the entire rotation. On the whole, it can not be said that the extremely rapid regeneration of aspen gives it any particular advantage ove conifers in forest management.

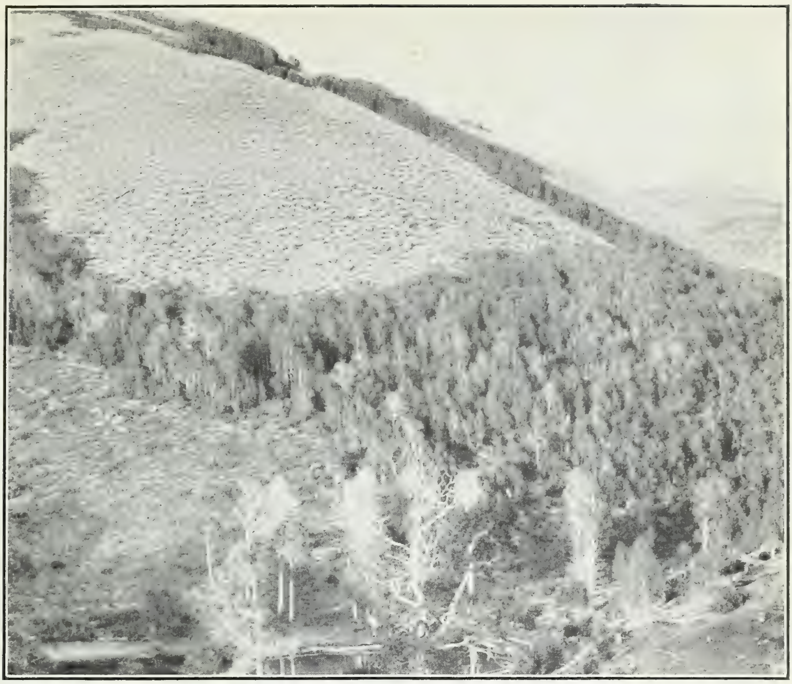
THE STAND

Aspen exists typically in even-aged stands (unusually over 40 years of age) in the Utah region, indicating their origin from burns. Two-storied stands are also common, an even-aged overwood with either an even-aged underwood, found where light fires have run through aspen, or with an uneven-aged underwood, found when the overwood begins to break up naturally. With the elimination of fire this last form of stand is becoming increasingly prevalent. (Pl. VII, fig. 1.) All-aged stands are also found. Even when an even-aged stand goes to pieces naturally, tree by tree, the new growth tends toward the even-aged, for the period of decadence of the parent stand is usually of relatively few years and the reproduction will contain only an approximately equal number of age classes. This partially uneven-aged stand will mature much more unevenly than its parent did, however, and its successor will be still more uneven-aged until at last a fully all-aged stand is formed.

ASSOCIATED SPECIES

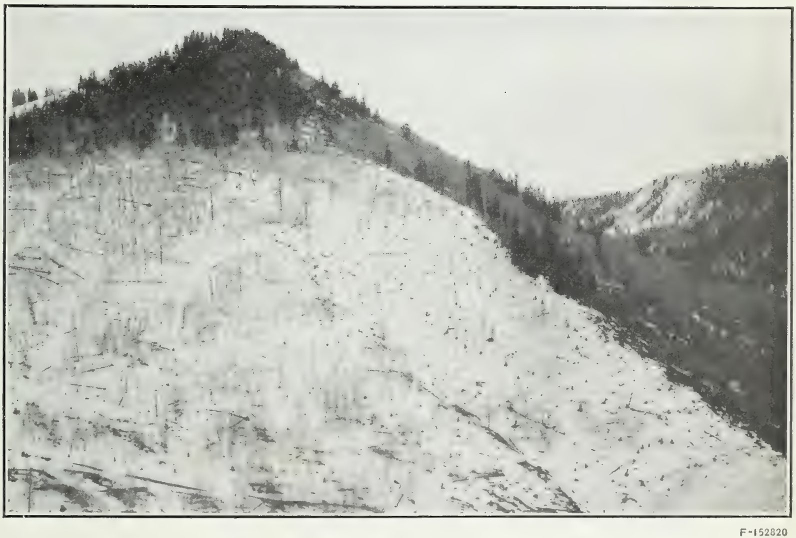
Aspen stands often give the appearance of permanence (climax type) on account of their purity over large areas, but there is little evidence that this is due to anything but fires in the past and slow seeding in of conifers at the present time. Nevertheless, as a management type a great many areas must be considered permanent for a very long period of years. Douglas fir, white fir, and lodgepole pine are typical associates of aspen throughout the Rocky Mountain region. Alpine fir, Englemann spruce, and the conifers which seldom form stands, such as limber pine and bristle-cone pine (*Pinus aristata*), are less frequent associates. All parts of the type can logically be occupied by some of these species to the exclusion of aspen as a type, although total exclusion of all aspen trees is hardly possible in the open coniferous stands of this dry region (Pl. VII, fig. 2).

Among the more common brushy associates are snowbrush (*Symphoricarpos oreophilius*), very common in the Utah region; myrtle



F-61260

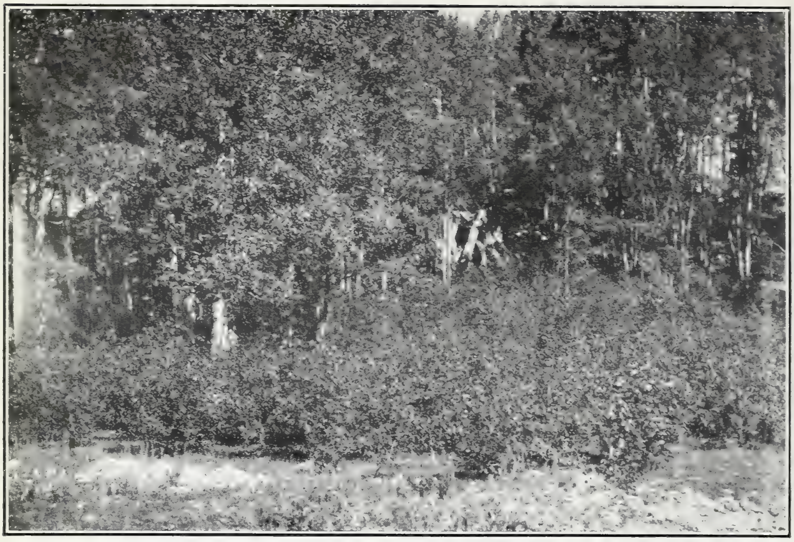
FIG. 1.—THIS HILLSIDE SHOWS THE TYPICAL SHARP EDGES OF THE ASPEN TYPE DUE TO ITS INABILITY TO SPREAD EXCEPT SLOWLY BY ROOT SUCKERS. WASATCH NATIONAL FOREST, UTAH



F-152820

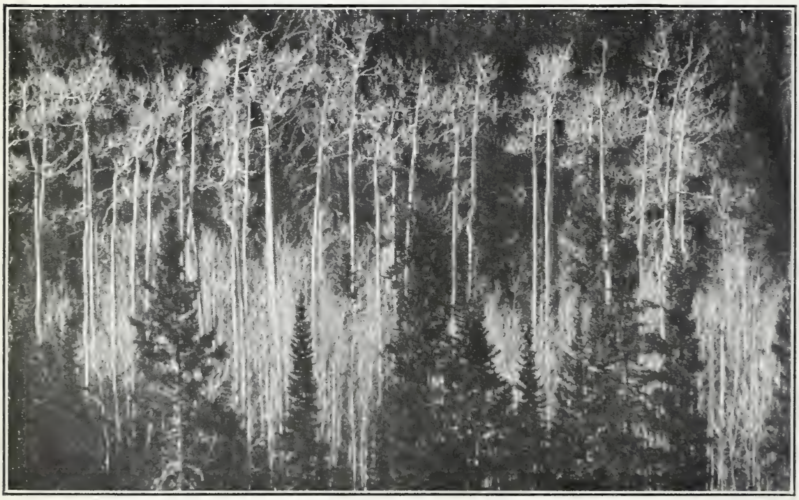
FIG. 2.—ASPEN ON A RECENT BURN

Note its absence from the right-hand part of the burn where the original stand was dense enough to crowd out the aspen entirely



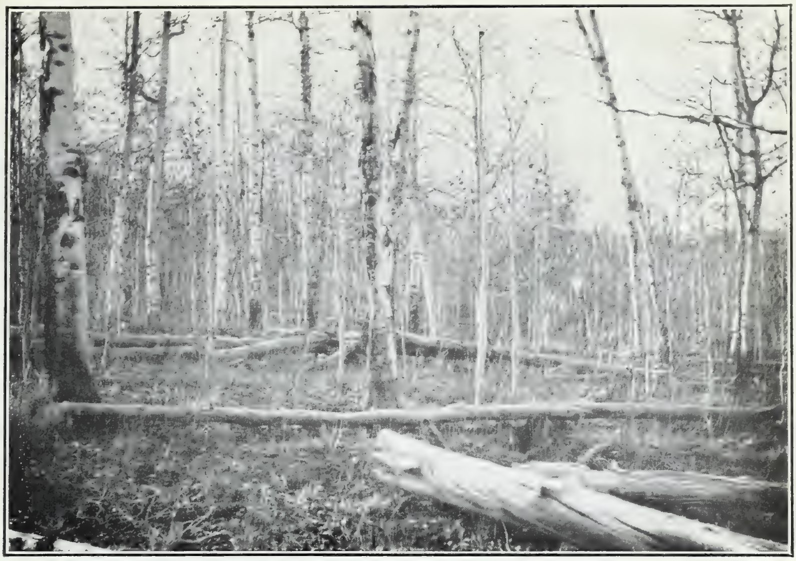
F-152823

FIG. 1.—THE YOUNG GROWTH IN THE FOREGROUND IS THE VANGUARD OF AN ASPEN INVASION OF OPEN GROUND BY ROOT-SUCKERING. MANTI NATIONAL FOREST, UTAH



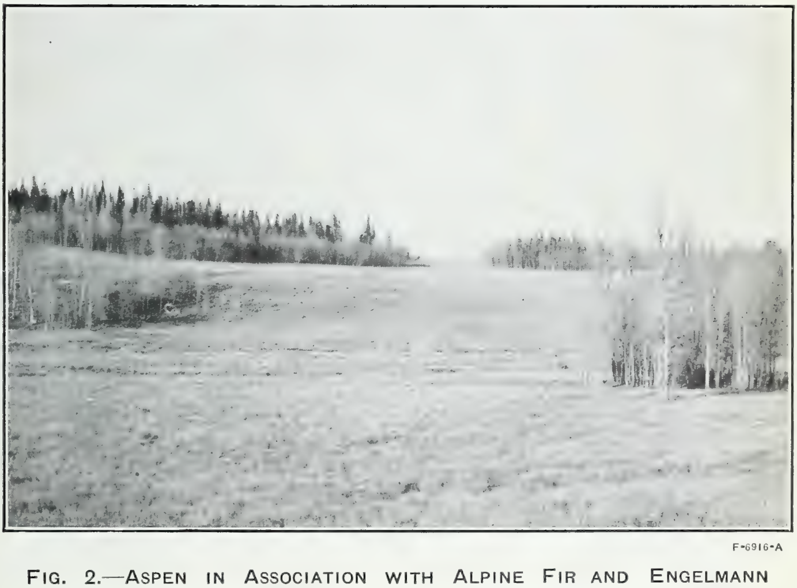
F-39935-A

FIG. 2.—A TWO-STORIED ASPEN STAND RESULTING FROM A LIGHT FIRE WHICH KILLED SOME OF THE OLDER TREES AND STIMULATED RAPID SPROUTING



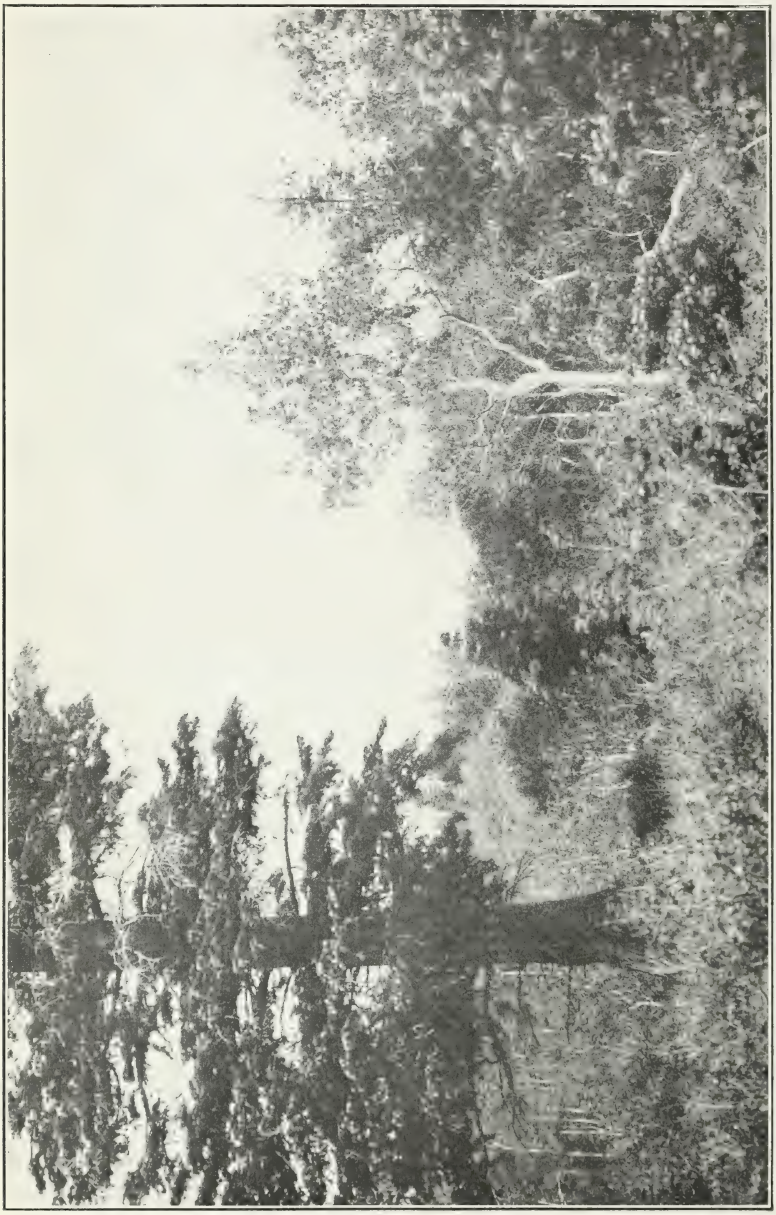
F-32457

FIG. 1.—OLD EVEN-AGED ASPEN STAND BREAKING UP, AND REPRODUCING WITHOUT THE AID OF FIRE, BEGINNING AN UNEVEN-AGED STAND



F-6916-A

FIG. 2.—ASPEN IN ASSOCIATION WITH ALPINE FIR AND ENGELMANN SPRUCE, WHICH ARE CROWDING THE ASPEN OUT EXCEPT ON THE EDGE OF THE OPENING



F-152811

RELATIVE DEVELOPMENT OF WHITE FIR AND ASPEN ON A POOR SITE (ASPEN QUALITY 5). THE ASPEN AND FIR ARE BOTH NEARLY MATURE brush (*Pachystima myrsinites*); Oregon grape (*Odostemon repens*), particularly at lower altitudes; and buffalo berry (*Lepargyrea canadensis*). Sagebrush (*Artemisia* spp.) and oak (*Quercus gambelii*) are unable to grow under aspen shade, but frequently fringe aspen stands. Maples (*Acer glabrum* and *A. grandidentatum*) are found occasionally, particularly in wet places, and chokecherry (*Prunus melanocarpa*) is common in the aspen zone both in the direct shade of aspen and in the open. Much the same is true of serviceberry (*Amelanchier alnifolia*), but which goes to much lower elevations than aspen. Mountain ash (*Sorbus sambucifolia*) is common in many places at higher elevations in the spruce-fir type. Owing to the wide extent of the aspen type, a vast number of herbaceous species are characteristic associates of aspen in the different regions, but none can be selected which is characteristic of aspen areas in general. As a class they are moisture-loving perennials and annuals, both herbs and grasses.

GROWTH

In all discussion of growth and development of aspen, the factor of site must constantly be kept in mind on account of the sensitiveness of aspen to site factors. Height growth is most seriously affected; indeed, this has been made the measure of site differences. Diameter growth is slower on poor sites also, although it is not reduced as fast as height growth; and accordingly on poor sites the height is less for a given diameter than on good sites where the trees are remarkably tall and slender. The average development of trees on a limited area of site quality 1 in central Utah, shown in Table 12, indicates the best that can be expected of aspen in the central Rocky Mountain region.

TABLE 12.—*Growth of aspen, Clear Creek, Utah*

Age	Diameter breast height[1]	Height[2]	Age	Diameter breast height[1]	Height[2]
	Inches	*Feet*		*Inches*	*Feet*
10 years	1.8	12.5	90 years	9.7	66.0
20 years	3.0	21.0	100 years	10.6	68.5
30 years	4.2	30.0	110 years	11.4	71.5
40 years	5.0	38.0	120 years	12.0	73.5
50 years	6.0	45.5	130 years	12.6	74.5
60 years	7.0	52.5	140 years	13.2	75.0
70 years	7.9	57.5	150 years	13.8	75.5
80 years	8.8	64.0			

[1] Basis, 261 trees. [2] Basis, 124 trees.

HEIGHT GROWTH

Height growth is extremely rapid during the first few years, provided the sprouts have full light. The rapidity of this growth is especially marked when compared with the slowness of conifers associated with aspen. The average height growth of aspen sprouts from four clear-cut areas is fairly representative of sprout growth on sites 1, 2, and 3, early growth being much less dependent on site than is more mature development (Table 13).

TABLE 13.—*Height growth of sprouts*

Age	Height	Age	Height
	Inches		*Inches*
1 year	15. 1	5 years	[1] 55. 9
2 years	27. 5	6 years	[1] 60. 0
3 years	41. 4	7 years	[1] 62. 7
4 years	50. 8		

[1] Estimated on basis of one plot only. Slow growth the seventh year is due chiefly to serious frost damage which even killed back sixth years' growth in some cases.

After the first rapid growth is over, however, the height growth of aspen slackens materially, while the conifers of equal age are in full vigor. The results of the differences in rate of height growth between aspen and the associated conifers is shown in Table 14.

It will be noted that alpine fir is able to equal the height of aspen on site quality 2 in 150 years; and that in time all the conifers approximate or exceed the maximum height of aspen, although, owing to its rapid juvenile growth, they are not able to overtake the aspen before it dies. On site quality 1 even alpine fir is probably unable to catch up with aspen before the aspen dies, although its final height is greater. On sites poorer than quality 2 the conifers undoubtedly fare relatively better, although data are lacking for a close comparison of aspen and conifer development.

TABLE 14.—*Height growth of aspen compared with that of conifers*

Age	Height				
	Aspen, Site 2 [1]	Douglas fir [2]	White fir [2]	Alpine fir [2]	Engelmann spruce [3]
	Feet	*Feet*	*Feet*	*Feet*	*Feet*
10 years	10	0. 6	0. 6	0. 6	
20 years	16	2	2	2	4
30 years	24	5	4	4	5
40 years	31	10	7	9	6
50 years	37	16	12	17	7
60 years	43	24	22	28	9
70 years	48	30	28	37	12
80 years	53	35	33	43	16
90 years	57	39	37	48	22
100 years	60	43	41	53	29
110 years	62	46	44	57	36
120 years	64	49	47	60	43
130 years	65	52	50	63	50
140 years	67	55	53	66	55
150 years	68	57	55	68	60
160 years		59	57	70	63
170 years		61	59	71	66
180 years		63	61	72	69
190 years		65	63	73	72
200 years		67	65	74	75

[1] Results from plots of site quality 2, measured for yield.
[2] Results from conversion of diameter growth (Table 14) into terms of height growth, by diameter-height tables.
[3] From Forest Service Circular 170, "Engelmann spruce in the Rocky Mountains," p. 10.

DIAMETER GROWTH

The advantage possessed by aspen in the matter of height growth is much less pronounced when it comes to diameter growth, since aspen grows very slowly toward maturity. Conifers, on the other hand, maintain a rapid diameter growth to old age and put on their widest rings at diameters of 12 to 15 inches, at which time aspen stagnates and decays.

Diameter growth for conifers as presented in Table 15 is in virgin stands of moderate density and probably represents a lower figure than would be obtained under forest management. This is of course true for aspen, though in a lesser degree.

TABLE 15.—*Diameter growth of aspen and associated conifers*

Age	Diameter breast high				
	Aspen, Site 2[1]	Douglas fir[2]	White fir[2]	Alpine fir[2]	Engelmann spruce[3]
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
10 years	0.8				
20 years	1.4				
30 years	2.4	0.2			
40 years	3.3	1.7	1.7	1.7	0.8
50 years	4.3	3.5	3.2	3.1	1.6
60 years	5.3	5.5	4.5	4.5	2.5
70 years	6.4	7.0	5.9	6.0	3.4
80 years	7.4	8.5	7.3	7.7	4.3
90 years	8.4	9.7	8.7	9.3	5.2
100 years	9.3	10.8	9.7	10.5	6.2
110 years	9.9	11.7	10.8	11.8	7.0
120 years	10.3	12.6	11.8	13.0	7.9
130 years	10.8	13.4	12.8	14.0	8.6
140 years	11.3	14.3	13.7	14.9	9.4
150 years	11.8	15.0	14.6	15.7	10.1
160 years		15.7	15.5	16.5	10.8
170 years		16.4	16.3	17.1	11.5
180 years		17.1	17.1	17.6	12.2
190 years		17.7	17.9	18.1	12.9
200 years		18.3	18.7	18.5	13.7
210 years			19.4		
220 years			20.1		
230 years			20.8		
240 years			21.4		
250 years			22.0		

[1] Heights (Table 13) converted into terms of diameters by use of diameter-height relation table (Table 7). Does not agree with column 4 Table 16 because that table shows average diameter of entire stands (over 4 inches diameter breast height), while this shows individual trees.

[2] From stump ring counts made on Manti National Forest. Basis: 51 Douglas firs, 62 white firs, 24 alpine firs.

[3] From Forest Service Circular 170, "Engelmann Spruce in the Rocky Mountains."

VOLUME GROWTH

Volume growth for individual trees is, of course, a product of the height and diameter growth. As diameter measurements include the bark, they tend to give conifers a certain fictitious advantage over aspen in diameter growth, and the development of solid wood in conifers is correspondingly slower than would appear from the diameter-growth table. The form of aspen is somewhat fuller-boled than conifers, which gives it another small advantage. For the quick production of large volumes of small wood in a short time, conifers can not compete with aspen on first-class sites (Table 16).

TABLE 16.—*Volume growth of aspen and associated conifers, inside of bark*

Age	Cubic feet (entire tree)				
	Aspen site 2 [1]	Douglas fir	White fir	Alpine fir	Engelmann spruce
10 years					
20 years	0.1				
30 years	.3				
40 years	.9	0.5			
50 years	1.9	1.0	0.6	0.6	
60 years	3.0	1.6	1.1	1.1	0.1
70 years	4.8	2.8	2.0	2.4	.2
80 years	6.5	4.5	3.4	5.0	.6
90 years	9.1	6.5	5.2	8.0	1.2
100 years	11.5	8.8	7.4	12.0	2.0
110 years	13.5	11.3	9.6	16.0	3.6
120 years	14.8	14.1	12.1	19.8	5.4
130 years	16.8	16.9	15.0	23.6	6.4
140 years	18.4	19.8	17.7	27.6	9.8
150 years	20.4	22.5	20.8	31.5	12.5
160 years		25.5	24.3	35.5	15.2
170 years		28.3	27.6	39.4	18.0
180 years		31.7	31.4	43.2	21.4
190 years		35.6	35.6	47.0	24.4
200 years		40.5	40.9	51.0	30.5

[1] Prepared from Tables 14 and 15 with volume tables shown in Appendix.

YIELD

The yield per acre depends on the volume of the individual trees making up the stand and the number of trees per acre. In making a comparison between conifers and aspen, it is much easier to compare volumes of trees than numbers per acre, since aspen develops typically as an even-aged stand while conifers are more often uneven-aged. In the intermountain region, where coniferous stands are open and reproduction is not plentiful, these stands are more likely to be understocked than are the aspen areas. The Douglas-fir type, furthermore, has been heavily culled over and virgin stands are rare. The potentialities of this type under management are almost impossible to determine.

The yield of aspen on sites 1 to 4 is shown in Table 17, and the mean annual increment per acre of aspen in different classes of products in Table 18.

TABLE 17.—*Empirical yield table for even-aged aspen stands*

SITE 1

Age	Entire stand	Main stand [1]						
					Volume per acre [2]			
	Trees per acre	Trees per acre	Average diameter breast high	Basal area	Total [3]	Cordwood [4]	Mine props [5]	Saw timber [6]
			Inches	*Square feet*	*Cubic feet*	*Cubic feet*	*Linear feet*	*Board feet*
30 years	1,600	710		76	300			
40 years	1,300	1,000	4.5	124	1,350	850		
50 years	960	750	5.3	136	2,250	1,550	3,400	600
60 years	750	610	6.1	144	3,000	2,200	6,200	2,600

[1] Trees more than 4 inches in diameter breast high.

[2] Gross volume without cull factor of any kind.

[3] Includes total volume of all trees more than 4 inches in diameter breast high.

[4] Includes total volume of all trees 6 inches diameter breast high and over, to a top-diameter limit of 5 inches.

[5] Includes all trees 7 inches to 11 inches in diameter at breast height. Merchantable length taken to 5 inches inside bark in tops.

[6] Includes all trees 10 inches and over diameter at breast height. Merchantable length taken to a 9-inch diameter limit in tops.

Table 17.—*Empirical yield table for even-aged aspen stands*—Continued

SITE 1—Continued

Age	Entire stand	Main stand						
	Trees per acre	Trees per acre	Average diameter breast high	Basal area	Volume per acre			
					Total	Cord-wood	Mine props	Saw timber
			Inches	*Square feet*	*Cubic feet*	*Cubic feet*	*Linear feet*	*Board feet*
70 years	610	520	7.0	148	3,550	2,750	8,700	4,800
80 years	500	450	7.8	154	4,050	3,250	10,700	6,800
90 years	410	380	8.7	161	4,500	3,600	10,700	9,000
100 years	340	360	9.5	166	4,850	4,000	9,000	11,000
110 years	290	290	10.4	172	5,100	4,300	6,000	13,200
120 years	250	250	11.2	177	5,350	4,600	4,200	15,400
130 years	220	220	12.1	181	5,600	4,900	2,800	17,400
140 years	200	200	13.0	184	5,950	5,150	1,800	19,600
150 years	190	180	13.8	186	6,100	5,400	1,000	21,600
SITE 2								
30 years	5,600	220	----------	14	----------	----------	----------	----------
40 years	3,400	650	4.0	78	500	150	----------	----------
50 years	1,200	900	4.8	114	1,350	750	----------	----------
60 years	940	710	5.4	124	2,100	1,300	3,500	600
70 years	730	580	6.1	132	2,750	1,750	6,500	2,000
80 years	580	490	6.8	140	3,250	2,200	8,500	3,400
90 years	460	400	7.5	146	3,650	2,600	9,500	4,800
100 years	380	330	8.2	152	4,000	2,900	8,000	6,200
110 years	320	270	8.9	158	4,300	3,200	4,500	7,600
120 years	270	210	9.6	162	4,550	3,400	2,700	9,000
130 years	240	160	10.2	166	4,750	3,650	1,500	10,400
140 years	210	110	10.9	170	4,900	3,850	600	11,800
SITE 3								
50 years	2,500	700	4.1	72	500	200	----------	----------
60 years	1,120	800	4.7	104	1,300	550	600	----------
70 years	850	650	5.3	114	1,950	950	4,000	150
80 years	670	520	5.8	122	2,500	1,250	6,400	1,000
90 years	530	410	6.5	128	2,950	1,600	7,900	1,600
100 years	440	320	7.1	134	3,300	1,850	5,300	2,200
110 years	360	240	7.7	138	3,600	2,100	2,400	2,800
120 years	310	170	8.3	142	3,850	2,300	1,200	3,600
130 years	260	100	8.9	146	4,050	2,500	400	4,200
SITE 4								
60 years	1,430	740	4.2	70	400	50	----------	----------
70 years	1,030	700	4.8	92	1,000	400	1,800	----------
80 years	800	550	5.3	104	1,600	750	4,000	200
90 years	620	430	5.8	110	2,050	1,050	3,500	300
100 years	500	320	6.3	116	2,400	1,300	1,800	400
110 years	410	220	6.9	120	2,700	1,550	700	600
120 years	340	140	7.4	124	2,950	1,700	100	800

TABLE 18.—*Mean annual increment per acre of aspen in different classes of products*

SITE 1

Age	Total volume	Cordwood	Mine props	Saw timber
	Cubic feet [1]	*Cubic feet* [1]	*Linear feet* [1]	*Board feet* [1]
30 years	10.0	----------	----------	----------
40 years	33.7	21.2	----------	----------
50 years	45.0	31.0	68	12.0
60 years	50.0	36.6	103	43.3
70 years	50.7	39.2	124	68.5
80 years	50.6	40.6	134	85.0
90 years	50.0	40.0	119	100.0
100 years	48.5	40.0	90	110.0
110 years	46.3	39.0	55	120.0
120 years	44.5	38.3	35	128.3
130 years	43.0	37.6	21	133.8
140 years	42.5	36.7	13	140.0
150 years	40.6	36.0	7	144.0

SITE 2

Age	Total volume	Cordwood	Mine props	Saw timber
40 years	12.5	3.2	----------	----------
50 years	27.0	15.0	----------	----------
60 years	35.0	21.6	58	10.0
70 years	39.2	25.0	93	28.5
80 years	40.6	27.5	106	42.5
90 years	40.5	28.8	105	53.3
100 years	40.0	29.0	80	62.0
110 years	39.0	29.0	41	69.0
120 years	37.9	28.3	23	75.0
130 years	36.5	28.0	12	80.0
140 years	35.0	27.5	4	82.8

SITE 3

Age	Total volume	Cordwood	Mine props	Saw timber
50 years	10.0	4.0	----------	----------
60 years	21.6	9.1	10	----------
70 years	27.8	13.5	57	2.1
80 years	31.2	15.6	80	12.5
90 years	32.7	17.7	88	17.7
100 years	33.0	18.5	53	22.0
110 years	32.7	19.0	22	25.4
120 years	32.0	19.1	10	30.0
130 years	31.1	19.2	3	32.3

SITE 4

Age	Total volume	Cordwood	Mine props	Saw timber
60 years	6.6	0.8	----------	----------
70 years	14.2	5.7	25	----------
80 years	20.0	9.4	50	2.5
90 years	22.7	11.6	39	3.3
100 years	24.0	13.0	18	4.0
110 years	24.5	14.0	6	5.4
120 years	24.5	14.1	1	6.6

[1] See footnote, Table 17, for sizes of materials included. The line across the table shows the probable pathological rotation. (Determined by Dr. E. P. Meinecke for site 2, and estimated for other sites.)

Tables 17 and 18 show the whole life history of aspen stands on sites 1 to 4, and indicate the great variability of development on these four sites. These tables are the result of specific observations, and the curves were necessarily made independently of each other and upon a slender basis at times. A close inspection will show discrepancies, but these are unavoidable in tables built up in this manner.

Table 18 indicates that on good sites (1 and 2) the question of disease as affecting rotation can be dismissed, unless aspen saw timber is to be raised, in which case the rotation will have to be determined by the length of time the timber will remain reasonably sound rather than by the culmination of increment—that is, gross increment—without any cull factor to allow for decay as is shown in this table. As the sites grow poorer the culmination of increment advances to higher age classes and the pathological rotation drops, so that on sites 3 and 4 the soundness of the timber will be the prime consideration in determining the rotation.

The yield of conifers associated with aspen can not be closely gauged for reasons already mentioned. Several stands of aspen and conifers growing under the same conditions side by side have been studied, with the results shown in Table 19.

TABLE 19.—*Comparison of yields of conifers and aspen*

Site quality	Age of stand		Present volume		Mean annual increment		Volume, average tree	
	Aspen	Conifer	Aspen	Conifer	Aspen	Conifer	Aspen	Conifer
			Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
1	68 years	105 years	4,000	3,757	58.8	35.8	12.3	15.2
2	40 years	Uneven	1,020	1,719	25.5	21.3	1.8	13.7
3	60 years	do	1,100	1,028	18.3	15.1	1.42	8.5
4	44 and 88 years.	do	660	1,642	15.1	13.9	.59	8.7
5	43 years	do	270	1,482	6.3	9.03	.45	9.4

Table 19 indicates that the mean annual increment of aspen and conifers is approximately the same when middle-aged aspen stands and all-aged conifers stands are compared, that is, the actual amount of wood produced is about the same for both species, although conifers have a small advantage on poor sites. The two respond in a very different way, however, as the growth conditions become poorer. Aspen trees become much reduced in individual development as the number of trees per acre increases, approaching as a limit the familiar aspen thicket type. (Pl. VIII.) The individual development of conifers is reduced much more slowly, but decrease in the number per acre leads to open park-like stands at the limits of the coniferous type. As far as the production of merchantable saw timber is concerned, the conifers naturally have an immense advantage.

THINNING

The extreme density of many young aspen stands suggests at once the possibility of getting a much better production of larger-sized wood by judicious thinnings. As a matter of fact, the possibility of getting stimulated growth by thinning does not seem to be very encouraging, although no stands exist which have been properly thinned from their youth to maturity. The chief practical difficulty lies in the small size of the material which must be removed, as it is very apparent that thinnings must be started early in the life of an aspen stand. A series of plots in aspen averaging from 3 inches to 7 inches in diameter (40 to 70-year-old stands) has been thinned, and the results five years later have been observed.

The results, reduced for the sake of simplicity to a common basis of 100 as the volume of the original stand on each plot, are shown in Table 20.

TABLE 20.—*Effect of thinning aspen. (Percentage of original volume.)*

Grade thinning	Original average diameter breast high	Cut	Left	Died 5 years	Remaining after 5 years	Total yield green	Total yield, including dead
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
A	3.01	12	88	0	106	118	118
None	3.24	0	100	3	117	117	120
A	3.06	10	90	1	103	113	114
None	3.80	0	100	8	103	103	111
A [1]	4.52	12	88	2	92	104	106
None [2]	5.10	0	100	6	102	102	108
B	3.07	21	79	1	89	110	111
None	2.91	0	100	15	97	97	112
B	4.23	19	81	0	91	110	110
None	5.10	0	100	6	102	102	108
C	5.72	21	79	1	86	107	108
None	5.90	0	100	5	105	105	110
C	4.50	24	76	2	79	103	105
None	5.10	0	100	6	102	102	108
C	3.73	23	77	2	96	119	121
None	3.43	0	100	14	99	99	113
Average:							
Thinned		17	83	1	93	110	111
Unthinned		0	100	8	103	103	111
Cleaned	2.96	13	87	6	93	106	112
None	2.56	0	100	7	103	103	110

[1] See Plate IX, Figure 1.

[2] See Plate IX, Figure 2.

The net result of thinning is to get the aspen in a green state rather than dead, which is not worth the labor expended in thinnings; for material this size is no more valuable green than dead, being generally unmerchantable in either case. Only four plots out of the nine show a larger total yield on the thinned plot. No analysis of conditions of site, age, or degree of cutting explains the matter, which seems to be mere chance. The figures show very plainly the slowness of net growth in aspen at ages of 40 to 80 years. Competition is very strong at that time, and in two cases an actual reduction in volume in the 5-year period is shown on account of heavy mortality in the suppressed class. On the average, an increase of only 3.3 per cent is shown in five years, or an annual increment of 0.6 per cent, while the yield table indicates an increment percentage of about 1.5 at this age. The discrepancy is largely due to the fact that the yield table takes into account only the stand more than 4 inches in diameter breast high, which is increasing rapidly at about that age on account of large accessions from below the 4-inch class.

The reason why thinnings fail to show stimulated growth is that the stimulation is in the smaller-sized trees the volume of which is small, while the largest trees show little or no acceleration, or even reduced increment, after thinning.

Aspen does not recover readily from suppression, as is shown by the loss by death in nearly all thinning plots during the 5-year period after treatment. In every case death was clearly the result of suppression before thinning, which reduced the vitality so markedly that even with much increased light after thinning death ensued.

PROPERTIES OF THE WOOD

The wood of aspen is straight-grained, of a smooth texture, white in color, and light when dry. The pith rays and annual rings are inconspicuous, and the pores are small and diffused evenly throughout the annual growth ring. The green wood contains a very large percentage of water, the weight of the green wood being about double that of the kiln-dry. It is therefore particularly desirable to cut this timber and allow it to dry a considerable time before hauling. Aspen cut in the winter or spring and peeled is in good condition to haul in the fall; if not peeled it will not be very dry until the following fall. Many sticks of unbarked aspen in piles sprout and bear leaves during the entire growing season after cutting. Green aspen will float, its weight being about 46 pounds per cubic foot.

Laboratory tests (Table 21) indicate that aspen from Wisconsin and New Mexico) is equal or superior in its chief mechanical properties to several of our western conifers, and has a higher value than alpine fir or even Englemann spruce in these respects.

TABLE 21.—*Mechanical properties of aspen and associated conifers*

	Aspen	Douglas fir	White fir	Alpine fir	Engelmann spruce
Weight	ML	ML	L	L	L.
Strength as beam or post	W	MW	MW	W	W.
Hardness	S	MS	MS	S	S.
Shock resistance	MG	MP	P	VP	P.
Stiffness	L	MS	MS	L	L.
Shrinkage	MS	do.	do.	S	MS.

Weight: L—light; ML—moderately light.
Strength: W—weak; MW—moderately weak.
Hardness: S—soft; MS— moderately soft.
Shock resistance: MG—moderately good; MP—moderately poor; P—Poor; VP—very poor.
Stiffness: L—limber; MS—moderately stiff.
Shrinkage: S—small; MS—moderately small.

USES

Aspen wood is especially suited to the manufacture of paper pulp, match sticks, and excelsior. As yet none of these industries has called upon the intermountain region for supplies of wood. The paper-pulp industry in the past called for large mills located in regions where they might operate for a long time. Plentiful supplies of water are also needed. Any suitable location in the Rocky Mountain region necessitates a longer railroad haul for much of the timber than has been financially attractive under past conditions. In view, however, of the growing conviction in the industry that domestic supplies of pulpwood must soon take the place of the somewhat uncertain Canadian supplies, the possibility of the profitable use of aspen from this and other localities seems clearer. In the match-stick business large logs of straight-grained wood are needed for the rotary veneer process used. These are found only in relatively small, widely scattered patches. Logging costs would be high and railroad hauls would be generally required. The amount of general manufacturing in the intermountain region requiring excelsior for packing its product is very small indeed, and the excelsior business could never develop very far until a greater demand was felt.

Aspen is used at the present time chiefly for mine props, firewood, and in miscellaneous ways in the round, as posts, poles, etc. It is occasionally sawed and is reputed to make superior bridge plank and stable flooring on account of its freedom from splintering. The early Morman pioneers made furniture from this wood to some extent. In general, it is not preferred to the conifers, except for posts, poles, and fuel.

Prop cutting takes trees from 7 to 11 inches in diameter breast high, the props running from 8 to 16 feet long and 5 to 10 inches inside of bark at the small end. A large use of aspen for mine props developed in 1913 to 1916 in the Utah coal fields, but of late years this has declined in favor of dry or even green lodgepole pine from Idaho. One reason for the preference for conifer props is their lighter weight when green or when waterlogged in wet mines, which makes them more suitable for reuse than aspen props.

Small poles from 3 to 8 inches in diameter breast high are used by ranchers near the mountains in a variety of ways. The larger sizes are frequently used for fence posts where cedar is not easily obtainable; for although aspen is not generally considered durable, it has a better reputation for durability in the soil than any of the conifers found in the region, except, of course, the junipers. Poles are also used for fences, corrals, and sheds built loosely and covered with straw for protecting cattle on exposed ranches. Their value for this purpose depends mainly on their long, straight lengths with little taper.

The firewood qualities of aspen are generally conceded to be superior to those of the conifers, which burn too rapidly when resinous, or make a poor, snapping fire in the case of nonresinous firs. The manner of growth of aspen makes it easy to handle as firewood. In some places remote from railroads aspen fuel is of notable value.

The future use of the aspen of the Rocky Mountain region is difficult to forecast. It is likely, however, that the wood will be used for special purposes to which it is peculiarly suited, as paper pulp or match wood, rather than for general purposes. There may always be certain consumption for various local uses, such as mine props and ties, posts, poles, and fuel, as at present. In the future, the Rocky Mountain aspen may be used for making excelsior and box shooks for fruit and canned goods.

LUMBERING AND LOGGING

Aspen logging is generally a simple process, carried on mainly by ranchers in slack season; but in case large sales should develop special logging crews would, of course, have to be used. The months of May and June and the early part of July are the most favorable for cutting, because at that time the bark can be peeled with ease. At other seasons it is the usual practice simply to ross the logs in narrow strips on four sides to facilitate drying. Hauling is most conveniently done in the fall or winter, after the peeled logs have dried during the summer. The reduction in weight is then very marked; for, although one of the lightest of woods when dry, green aspen is as heavy as dry oak or hickory.

The costs of logging run approximately as follows, on a linear foot basis (mine props):

Cost of logging per thousand linear feet:

Stumpage	$5.00
Cutting and peeling	3.33
Skidding	1.67
Hauling	10.00
Loading on cars	1.50
Total cost	21.50
Selling price	27.50

On a cord basis, including mostly trees too large for props, the cost is:

Stumpage	$0.75
Cutting	.90
Skidding	.30
Hauling	3.00
Loading	.20
Total	5.15

These figures apply to stands of aspen readily accessible from roads, not more than 12 miles from a railroad point. Merchantable stands are generally located in places easily logged, with little underbrush and easy slopes.

MANAGEMENT OF ASPEN, SILVICULTURAL SYSTEMS

The characteristics of aspen point unmistakably to a clear-cutting system. Thrifty stands are positively dependent upon clear cutting. (Pl. X, fig. 1.) Thinnings in merchantable stands are not to be considered advisable as improvements to the stand, but they may be encouraged as a matter of economy, since they mean the utilization of the inferior material before it dies of suppression. Scattered cuttings have the effect of a selection system, and the removal of this selected material may well be detrimental to the remaining stand, since we have seen that reproduction that comes under partial shade is weak, develops slowly, and is likely to be crooked and knotty and to decay early. (Pl. X, fig. 2.) For these reasons sales that will afford the utilization of the widest number of diameter classes are to be preferred, and sales of different classes ought to be concentrated in the same areas.

Brush disposal is not a serious question in aspen stands, for it has little bearing on reproduction and the fire hazard is practically negligible. With moderate lopping the brush disappears in about four years. Special methods of brush disposal, calculated to interfere with the free grazing of cut-over areas by sheep, have been advocated for the safeguarding of reproduction. Their worth is not proved, however; and for the present, where regeneration is desired, administrative restriction of sheep grazing and of cattle grazing to some extent is the better method on clean-cut areas or in places where very old stands are going to pieces naturally.

The rotations upon which aspen is to be managed will depend upon the site, the class of material desired, and the period during which aspen remains sound, which is itself largely controlled by site. Even on the best sites rotations of more than 80 years will be infrequent, particularly as the mean annual increment on these sites culminates at about this age, if the tree is used to a small diameter limit. Sometimes, however, it may be advisable to let the trees grow to 110 years. On poorer sites decay is the limiting factor, and trees should seldom be grown longer than 70 years. On sites 3, 4, and 5 there will usually be no merchantable yield, except for some special products employing exceptionally small diameters.

RELATIVE VALUES OF ASPEN AND CONIFERS IN MANAGEMENT

Aspen must be utilized to a low diameter to get the most out of it. Even on the best sites it will not run as high as conifers in saw-log material, although it requires rather less time to attain that size, and on second-quality sites the saw-log material is of very little importance. Utilization in the form of cordwood is, therefore, ideal for aspen, both for realizing the most out of the crop and as a means by which clean-cutting may be practiced.

Aspen stumpage values are lower than the stumpage values of the associated conifers, so that to bring in equal annual income the aspen must outstrip conifers in yield, or have secondary income to compensate for the lower value of its wood. Aspen saw timber stumpage brought about $1.50 per thousand feet board measure in 1922, as against $2.50 for Engelmann spruce and Douglas fir, and $1.50 for white fir and alpine fir. The mixed-conifer type has a stumpage value of about $2 per thousand on the average. Aspen sold for cordwood brings about 75 cents per cord stumpage, and for mine props, 0.5 cent per linear foot.

The general relations between the annual incomes from aspen and conifers can not, in the very nature of things, be worked out in detail on a money basis. Markets will always vary, and local conditions have a great bearing upon both yields and values. There are also secondary values of some degree or other possessed by every acre occupied by aspen or conifers, the chief of which is grazing. This runs about 14 cents per forage acre per annum for cattle and 11 cents for sheep, or an average of 12½ cents at present grazing rates (1923). There is more forage under aspen than under conifers on account of the lighter shade in stands.

Figuring the grazing return in terms of the site area, a careful approximation shows that aspen stands average 0.62 of a forage acre to the surface acre, yielding about 7.7 cents a surface acre. The average for conifers is 0.47 forage acre to the surface acre, yielding 5.9 cents. The return on conifer sites varies inversely with the density of stand, from 7 cents from 0.56 of a forage acre on areas yielding 1,000 feet per acre to 1.9 cents from 0.15 of a forage acre on areas of 9,000 feet per acre.

The aspen yield of 7.7 cents per acre per year must, however, be reduced slightly to allow for protection during the period of regeneration, an average of 5 years in every 80, or 6 per cent, leaving 7.2 cents per acre as the corrected value for grazing under aspen.

A fully stocked acre of conifers should run at least 12,000 feet per acre at maturity on site 1 in the aspen belt. Under the selection sys-

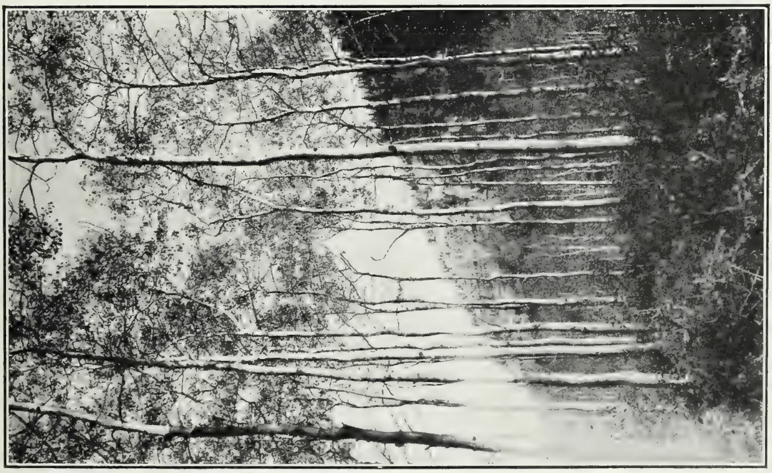


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FIG. 1.—THINNED

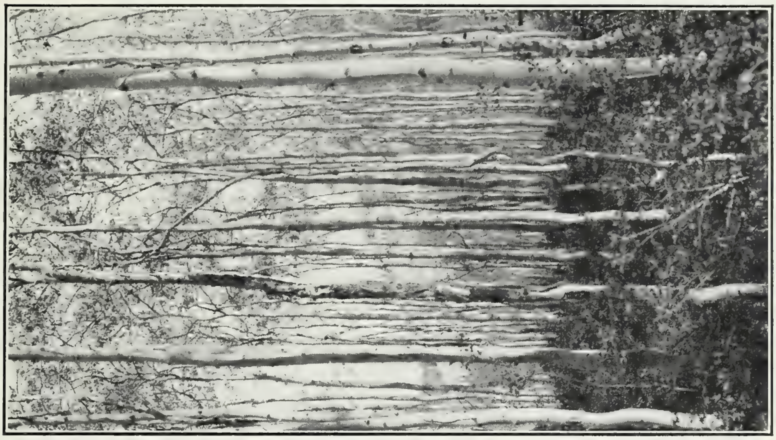

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FIG. 2.—UNTHINNED

Thinning in aspen stands

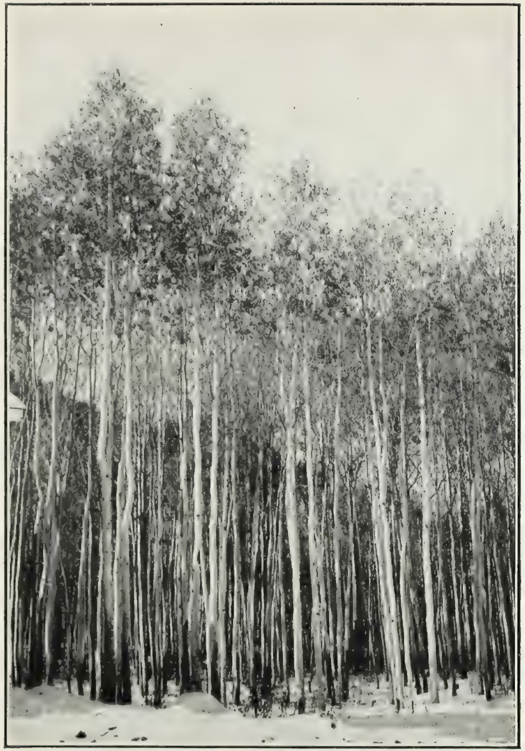

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FIG. 1.—A CLEAN CUTTING SYSTEM CAUSES A DENSE GROWTH OF VIGOROUS STRAIGHT TREES

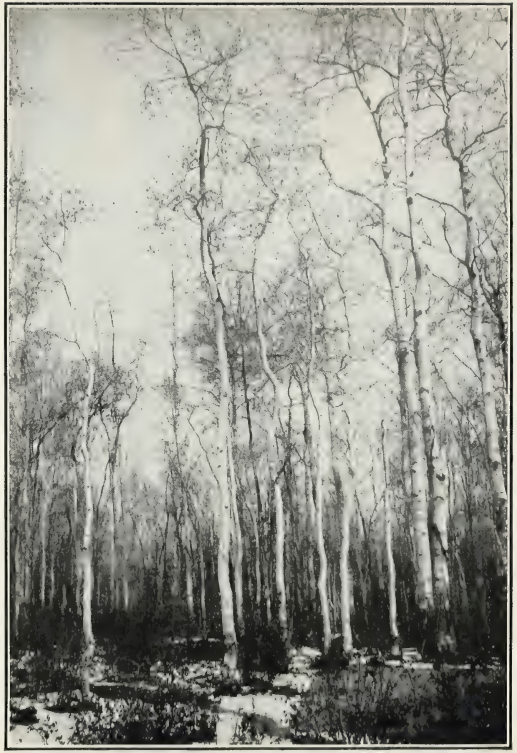

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FIG. 2.—A SELECTION SYSTEM CAUSES AN OPEN STAND OF POOR CROOKED TREES TO COME IN

Effects of different methods of cutting

tem probably 3,000 feet would be left after cutting, so that the average stand during the cutting cycle would be 7,500 feet. The grazing income under such conditions would be 2.7 cents per acre. As sites become poorer conifer stands become more open in the aspen region, so that forage values tend to rise as site quality deteriorates. Figured as above, the values of forage would amount roughly to 3 cents an acre on site 2, 3.3 cents on site 3, 3.8 cents on site 4, and 4.5 cents on site 5.

Another secondary and indirect value which differs in aspen and conifer stands is watershed protection. Conifers probably protect the soil against excessive erosion better than aspen, and they retard snow melting. The practical value lies mostly in the latter, however, for under proper forest management destructive erosion should never be found in either type. In the Douglas fir type the snow water is of little importance for direct irrigation, although it has great value for filling reservoirs. In the spruce-fir type the water stores are the largest, and as the snows melt last there they are the mainstay of irrigation. An even, prolonged flow is promoted by a conifer cover, which is distinctly more desirable than aspen. Owing to the lack of quantitative data regarding watershed protection and sustained run-off no monetary value can be assigned to this factor.

The cost of management is probably somewhat less in aspen stands than in conifers on account of the clean-cutting method, which makes the marketing of individual trees unnecessary and lightens timber-sale supervision. The differences will be inconsiderable, especially when distributed over an entire rotation.

Considering all the variations in primary and secondary monetary yields of the aspen and coniferous types, it is impossible to get more than a rough idea of how the types compare under different degrees of utilization. A rough comparison such as that shown in Table 22 may be made. It will be indicative of general conditions.

Table 22.—*Gross annual income (cents per acre) from aspen and conifers compared under different forms of management*

Utilization	Site				
	1	2	3	4	5
A. Forage:					
Aspen	7.2	7.2	7.2	7.2	7.2
Conifer	2.7	3	3.3	3.8	4.5
B. Saw timber [1]:					
Aspen	16.5	9.3	2.7	.4	--------
Conifer	29	17	12	11.2	7.2
C. Cordwood [2]:					
Aspen	23.2	13.9	8.5	6.1	--------
Conifer	21	10.6	6.1	5.2	1.5
D. Mine props: Aspen	67	52.5	44	25	--------
E. Total aspen yields:					
Saw timber+forage	23.7	16.5	9.9	7.6	7.2
Cordwood+forage	30.4	21.1	15.7	13.2	7.2
Mine props+forage	74.2	57.7	51.2	32.2	7.2
F. Total conifer yields:					
Saw timber+forage	31.7	20	15.3	15	11.7
Cordwood+forage	23.7	13.6	9.3	9	7

[1] Aspen $1.50 per thousand; mixed conifers $2 per thousand stumpage.

[2] Values in Table 19 reduced 7 cubic feet per acre to approximate cubic feet on a 5-inch limit (pulpwood). Stumpage $0.75 per cord for both aspen and conifers.

Yield of aspen and conifers on saw-timber basis.—The volume of conifers in board feet is usually about four times their volume in cubic feet, including the whole stem. This rough converting factor has been employed in estimating section B in Table 22, and the resultant figures here and in sections E and F make it clearly evident that, for saw timber, aspen can not compete with conifers, even when its large secondary grazing value is added and the greater value of conifers for watershed protection is disregarded.

Yields of aspen and conifers on cordwood basis.—If in the future the paper industry should develop in this region to such an extent that both aspen and the associated conifers would be in demand for pulping, aspen would probably have a little advantage over the conifers in production of solid volume of wood, except on the poorest sites. Still, under management, conifers ought to grow more densely than they now do, giving better annual increment, while aspen apparently can not be very much improved in this regard by management. The monetary income from aspen, if it has a stumpage value equal to conifers for pulp, would slightly exceed the income from conifers, while the secondary income from grazing would increase this difference. This is shown in sections C, E, and F of Table 22.

Aspen managed for cordwood and conifers for saw timber.—Comparison of sections B and C of the same table will show roughly the relation between these two forms of utilization. On the better sites the gross income including that for grazing, is virtually equal, but on poorer sites the conifers have a greater value. Excluding forage value, conifers are superior on all sites.

Yield of aspen and conifers for mine props.—Financial aspects of this form of management can not be gone into even in a rough way, on account of the entire lack of data on the yield of conifers under this form of management. The indications are that conifers would outstrip aspen in gross income from this form of production; for although it takes longer for the individual conifer to reach prop size than it does aspen, conifer props are more valuable, and the conifers are much more adaptable than aspen to a system of cutting that removes only a portion of the stand (trees 7 to 10 inches in diameter breast high). The smaller, partly suppressed aspen, under these circumstances, grows crooked and responds poorly after the cutting; whereas the more tolerant conifers maintain a straight trunk and respond quickly to partial cuttings.

Yield of conifer saw timber and aspen mine props.—It is possible to estimate roughly the gross income from these two forms of utilization. Section D of Table 22 shows the results from the management of aspen on a mine-prop basis. The mean annual increment at 80 to 90 years in terms of mine props is 134 linear feet per acre per annum on site 1, 105 linear feet on site 2, 88 linear feet on site 3, and 50 linear feet on site 4. In terms of money value, at a stumpage of 0.5 cent per linear foot, results are obtained as shown in Table 22.

It is apparent that aspen would be capable of bringing in far more income from mine props than any other form of utilization, were it to command a certain market, and also that this income would considerably exceed the best that conifers can show. This is not due to better production of this class of material by aspen, but depends on the higher stumpage rate obtained. Since the mine-prop market is limited and conifer props are preferred, it is not often possible to sell aspen to the mines.

A conifer log scaling 100 board feet and worth $0.20 at $2 stumpage contains about 17 cubic feet and is worth $0.0118 per cubic foot. An aspen prop 16 feet long is worth $0.08 at 0.5-cent per linear foot stumpage, and contains 4.3 cubic feet and is worth $0.0186 per cubic foot. The aspen is not only worth almost double the conifer, but in utilization for props very much less of the tree is wasted.

In general, the income from aspen is lower than from conifers on the same site. Aspen is a wood distinctly valuable for only a few purposes, and the entrance into this region of industries using aspen is problematical. Conifers, on the other hand, always have a broad general usefulness, and a permanent demand independent of special markets. There can be no point, therefore, in trying to maintain an aspen management type.

TRANSFORMATION OF ASPEN TYPE

The natural transformation of the aspen type over into a coniferous type is a very slow process. The rate of invasion of the conifers can very clearly be noted in places where single old trees stand in areas of pure aspen. In protected flats the seed spreads fairly uniformly from the parent trees to a distance of about 150 feet in all directions. On exposed ridges it will spread as far as 400 feet to the leeward and very slightly in other directions. In a 45-year-old aspen stand, where this rate of seeding in was carefully studied, the conifers were still only about 8 to 12 inches tall. It will not be less than 80 to 100 years before these trees begin to seed in turn to the leeward. The average progress of the conifer stand is therefore somewhat about 3 feet per year; but this is occasionally accelerated by seed that has by some chance been carried much farther than usual, and is forming a new point from which seedlings spread in turn. On the assumption that conifers found in the aspen zone will bear seed at 80 years, most areas ought to be well seeded in with reproduction in three tree generations or about 250 years in the Douglas fir-white fir zone, and 150 years in the Engelmann spruce-alpine fir zone. Certain areas in the lower zones may require more than 250 years to be transformed on account of their great extent and purity. On aspen areas at high elevations (site quality 5), the replacement by a conifer stand will practically never take place, conifers scattered among the aspen being the most that can be expected.

Transformation can be hastened artificially but at a rather high cost. Artificial regeneration has a certain advantage in that the more valuable species, Engelmann spruce and Douglas fir, can be given the advantage in each zone, while in natural invasions alpine fir and white fir are much more numerous. The cost of planting amounts to about $25 per acre, which if it is to be recovered in one rotation amounts to an annual charge of 12 cents on a 200-year rotation, no interest charges included. It is evident that a decided advantage of conifers over aspen must be demonstrated before any general plan for planting up aspen areas to conifers is embarked upon, and there must be a reasonable assurance that the advantage will last through at least one rotation. Planting of small areas of conifers in large aspen areas could be done at smaller expense and would serve to speed up greatly the replacement of aspen where natural stands of conifers are at great distances. The replacement which might naturally require 250 years could be reduced to about 80 by the establishment of three to four seed trees per acre at a cost of perhaps $2 per acre. This cost would be chargeable to the first merchantable crop, consisting not of the trees planted but of their offspring, which would presumably mature some 250 to 300 years after the planting. The annual charge would be only 0.6 cent per acre on this basis, but it presupposes, as before, the certain knowledge of the inferiority of aspen to conifers for all general and special purposes far into the future. Under present circumstances even this activity in artificial transformation would seem unwarranted, particularly in view of many unsuccessful plantings of Douglas fir, western yellow pine, and Engelmann spruce under aspen.

It must not be inferred that aspen is a hindrance to artificial reforestation, for the success of tolerant conifers is greatly increased by aspen cover. Results in the vicinity of the Great Basin Experiment Station in central Utah show this clearly (*10*).

On an area of aspen (site quality 2) at about 9,000 feet elevation, Engelmann spruce was planted under a virgin stand and also on areas where one-quarter, one-half, three-quarters, and all the timber had been removed. Five years after establishment:

61 per cent were alive under virgin stand.
29 per cent were alive where one-fourth of the stand was cut.
18 per cent were alive where one-half of the stand was cut.
11 per cent were alive where three-fourths of stand was cut.
1 per cent were alive where all timber was cut.

A similar series of plots under aspen at 7,800 feet elevation (site quality 4) in which Douglas fir was used, gave, after three years, the following results:

32 per cent were alive under virgin stand.
31 per cent were alive where one-fourth of stand was cut.
52 per cent were alive where one-half of stand was cut.
27 per cent were alive where three-fourths of stand was cut.
8 per cent were alive where all of stand was cut.

Experimental plantings indicate that Englemann spruce can be introduced with a fair degree of success in aspen stands within the spruce-fir type, except on south slopes. In general, growth on such plantations is less vigorous than in the open at high elevations. Douglas fir and western yellow pine can be planted with success, in years of favorable rainfall at least, in the lowest of the aspen, although the stands must usually be thinned within a few years to get the most rapid and vigorous growth, particularly in the case of western yellow pine.

APPLIED MANAGEMENT IN THE FIELD

The perpetuation of aspen stands is always advisable, for the forest cover has a great indirect value as a protection to watersheds and as a nurse tree to conifers, aside from any commercial value. Therefore, grazing should not be allowed to wipe out aspen under any circumstances, for aspen can not reclaim the lost areas again. Old even-aged stands without an understory of sprouts and cut-over areas must be watched with care to see that grazing does not prevent a new stand from coming in.

Concentrate cuttings on certain areas and make the cuttings as heavy as possible to bring about vigorous sprouting and a rapid growth of new trees.

Protect all young conifers in aspen from injury during logging. Do not allow isolated merchantable conifers in an aspen stand to be cut. The transformation of aspen type to conifers is desirable.

Utilize aspen for small material (poles, posts, cordwood, etc.), as it yields best on that basis, and cutting while young and small has no effect on reproduction as does the cutting of conifers before seeding age is reached. By using aspen when small, the losses from decay are also avoided.

APPENDIX

VOLUME TABLES

The three volume tables most frequently used are given hereafter: (1) Total volume of tree in cubic feet, used mostly in technical work dealing with growth and increment; (2) volume in cubic feet to a 5-inch diameter limit in the top, used in estimating cordwood or pulpwood; (3) volume in board feet to a 9-inch diameter limit in the top, used in estimating saw timber. The diameter limit is unusually large, because aspen will not often be cut primarily for saw timber, but more valuable products will as a rule be taken from the tops. Nine-inch saw log utilization presupposes the utilization of the tops for props or pulp, with saw logs as a by-product.

TABLE 23.—*Volume, aspen*[1]—*Total contents of tree inside of bark in cubic feet*

Diameter breast high	Total height of tree				
	40 feet	50 feet	60 feet	70 feet	80 feet
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
4 inches	1. 7	2. 1			
5 inches	2. 6	3. 2			
6 inches	3. 6	4. 4	5. 0		
7 inches	4. 8	5. 8	6. 6	8. 7	
8 inches	6. 0	7. 3	8. 5	10. 6	13. 3
9 inches	7. 4	9. 0	10. 6	12. 7	16. 2
10 inches	9. 0	10. 8	12. 9	15. 1	19. 5
11 inches	10. 7	12. 9	15. 3	18. 0	23. 2
12 inches	12. 5	15. 1	18. 0	21. 0	27. 5
13 inches	14. 6	17. 4	21. 0	24. 4	32. 0
14 inches	16. 8	20. 0	24. 1	28. 0	37. 0
15 inches	19. 2	23. 0	27. 6	32. 1	42. 2
16 inches	21. 7	26. 0	31. 2	36. 4	47. 8
17 inches	24. 4	29. 0	35. 0	40. 9	53. 7
18 inches	27. 3	32. 2	39. 0	46. 0	59. 8
19 inches		35. 6	43. 2	51. 0	66. 2
20 inches		39. 2	47. 7	56. 6	73. 0
21 inches			52. 5	62. 4	78. 8
22 inches			57. 5	69. 5	86. 4

[1] Tables 22 and 23 are based on 1,573 trees, Manti and Fishlake National Forests, Utah.

TABLE 24.—*Volume, aspen—Contents of tree* (*inside of bark*) *in cubic feet to a 5-inch top diameter limit*

Diameter breast high	Total height of tree				
	40 feet	50 feet	60 feet	70 feet	80 feet
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
6 inches	1. 9				
7 inches	3. 3	4. 0	4. 5	6. 2	
8 inches	4. 7	5. 8	6. 5	8. 5	11. 0
9 inches	6. 4	7. 7	9. 0	10. 8	14. 4
10 inches	8. 1	9. 7	11. 5	13. 4	18. 0
11 inches	9. 9	11. 9	14. 1	16. 7	22. 0
12 inches	11. 8	14. 2	17. 0	19. 8	26. 4
13 inches	14. 0	16. 6	20. 1	23. 4	31. 1
14 inches	16. 3	19. 3	23. 3	27. 1	36. 2
15 inches	18. 7	22. 4	26. 9	31. 3	41. 6
16 inches	21. 3	25. 5	29. 5	35. 7	47. 2
17 inches	24. 0	28. 5	34. 4	40. 3	53. 2
18 inches	26. 9	31. 7	38. 4	45. 4	59. 4
19 inches		35. 2	42. 7	50. 5	65. 8
20 inches		38. 8	47. 3	56. 1	72. 6
21 inches			52. 1	62. 0	78. 8
22 inches			57. 1	69. 1	86. 0

TABLE 25.—*Volume, aspen*[1]*—Board measure to 9-inch top limit (in tens of board feet). Scribner rule)*

Diameter breast high	Total height of tree				
	40 feet	50 feet	60 feet	70 feet	80 feet
11 inches	----------	2	2	4	5
12 inches	3	4	5	6	8
13 inches	4	5	6	9	12
14 inches	5	7	8	11	15
15 inches	7	9	11	14	18
16 inches	8	11	13	16	22
17 inches	10	13	15	18	26
18 inches	11	15	18	21	29
19 inches	----------	17	20	24	34
20 inches	----------	19	22	27	38
21 inches	----------	----------	24	31	42
22 inches	----------	----------	26	35	47

[1] Based on 675 trees, Manti and Fishlake Natural Forests, Utah.

The foregoing tables are basic and the ones most frequently used. Aspen is cut for many special uses and special tables reading in linear feet, cubic feet, or board feet may be needed in many instances. These may be prepared as needed from the taper tables which follow. Useful special tables based on site may be prepared by combining these tables with the height-diameter table (Table 2) in the text.

TABLE 26.—*Stem taper of aspen as shown by diameter inside of bark, central Utah*

TREES 40 FEET IN HEIGHT

Diameter breast high	Height from ground			
	Stump	10 feet	20 feet	30 feet
	Inches	*Inches*	*Inches*	*Inches*
4 inches	4.3	3.1	2.8	1.2
5 inches	5.2	4.3	3.4	2.1
6 inches	6.1	5.1	3.9	2.4
7 inches	7.1	5.9	4.5	2.8
8 inches	8.0	6.6	5.1	3.2
9 inches	8.9	7.4	5.7	3.6
10 inches	9.8	8.2	6.3	3.9
11 inches	10.7	8.9	6.8	4.3
12 inches	11.6	9.7	7.4	4.7
13 inches	12.5	10.4	8.0	5.0
14 inches	13.4	11.2	8.6	5.4
15 inches	14.3	12.0	9.1	5.8
16 inches	15.2	12.7	9.7	6.2
17 inches	16.1	13.5	10.3	6.5
18 inches	17.1	14.3	10.9	6.9

TABLE 26.—*Stem taper of aspen as shown by diameter inside of bark, etc.*—Con.

TREES 50 FEET IN HEIGHT

Diameter breast high	Height from ground				
	Stump	10 feet	20 feet	30 feet	40 feet
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
4 inches	4.3	3.6	3.1	2.2	1.6
5 inches	5.2	4.4	3.7	2.7	1.9
6 inches	6.1	5.2	4.4	3.2	2.2
7 inches	7.0	5.9	5.0	3.7	2.5
8 inches	7.9	6.7	5.7	4.2	2.8
9 inches	8.7	7.5	6.3	4.8	3.1
10 inches	9.6	8.3	7.0	5.2	3.4
11 inches	10.5	9.1	7.6	5.8	3.7
12 inches	11.3	9.8	8.2	6.3	4.0
13 inches	12.2	10.6	8.9	6.7	4.3
14 inches	13.0	11.4	9.5	7.2	4.6
15 inches	14.0	12.2	10.1	7.7	4.9
16 inches	14.9	13.0	10.8	8.2	5.2
17 inches	15.7	13.7	11.4	8.7	5.5
18 inches	16.6	14.5	12.1	9.2	5.8
19 inches	17.5	15.3	12.7	9.8	6.1
20 inches	18.3	16.0	13.3	10.2	6.4

TREES 60 FEET IN HEIGHT

Diameter breast high	Height from ground					
	Stump	10 feet	20 feet	30 feet	40 feet	50 feet
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
4 inches	4.4	3.6	3.0	2.5	1.8	1.2
5 inches	5.2	4.4	3.8	3.2	2.4	1.5
6 inches	6.0	5.2	4.4	3.7	2.8	1.8
7 inches	6.8	6.0	5.2	4.3	3.3	2.1
8 inches	7.7	6.8	5.9	4.9	3.8	2.4
9 inches	8.6	7.6	6.6	5.5	4.2	2.7
10 inches	9.4	8.4	7.3	6.0	4.7	3.0
11 inches	10.4	9.3	8.0	6.8	5.2	3.3
12 inches	11.2	10.0	8.7	7.3	5.6	3.6
13 inches	12.1	10.8	9.4	7.8	6.0	3.9
14 inches	13.0	11.6	10.1	8.5	6.6	4.2
15 inches	13.9	12.4	10.7	9.1	7.0	4.5
16 inches	14.7	13.2	11.4	9.6	7.4	4.8
17 inches	15.5	14.0	12.2	10.2	8.0	5.1
18 inches	16.5	14.8	12.8	10.8	8.4	5.4
19 inches	17.4	15.6	13.7	11.4	9.0	5.7
20 inches	18.2	16.5	14.4	12.0	9.4	6.0
21 inches	19.0	17.1	15.1	12.6	9.8	6.3
22 inches	20.0	18.0	15.8	13.2	10.3	6.6

TABLE 26.—*Stem taper of aspen as shown by diameter inside of bark, etc.*—Con.

TREES 70 FEET IN HEIGHT

Diameter breast high	Height from the ground						
	Stump	10 feet	20 feet	30 feet	40 feet	50 feet	60 feet
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
4 inches	4.2	3.8	3.4	3.0	2.3	1.8	1.1
5 inches	5.1	4.6	4.2	3.6	2.9	2.3	1.4
6 inches	6.0	5.5	5.0	4.2	3.4	2.7	1.7
7 inches	6.9	6.4	5.6	4.9	4.0	3.2	2.0
8 inches	7.7	7.1	6.4	5.5	4.6	3.6	2.3
9 inches	8.5	7.9	7.2	6.2	5.1	4.0	2.6
10 inches	9.3	8.6	7.8	6.8	5.6	4.5	2.9
11 inches	10.2	9.4	8.5	7.4	6.2	4.9	3.2
12 inches	11.1	10.1	9.1	8.0	6.7	5.3	3.5
13 inches	11.9	10.9	9.8	8.6	7.3	5.8	3.8
14 inches	12.7	11.7	10.6	9.2	7.9	6.2	4.0
15 inches	13.6	12.4	11.2	9.8	8.4	6.6	4.3
16 inches	14.4	13.2	11.9	10.4	8.9	7.1	4.6
17 inches	15.3	14.0	12.6	11.1	9.5	7.5	4.9
18 inches	16.2	14.9	13.4	11.8	10.0	7.9	5.2
19 inches	17.1	15.7	14.2	12.5	10.6	8.4	5.6
20 inches	18.0	16.6	14.9	13.1	11.2	8.8	5.8
21 inches	19.0	17.5	15.6	13.9	11.6	9.2	6.1
22 inches	20.0	18.5	16.5	14.6	12.2	9.7	6.4

TREES 80 FEET IN HEIGHT

Diameter breast high	Height from ground							
	Stump	10 feet	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
4 inches	4.2	4.0	3.6	3.4	3.0	2.6	2.2	1.6
5 inches	5.0	4.8	4.4	4.0	3.6	3.2	2.6	2.0
6 inches	5.9	5.6	5.2	4.8	4.3	3.7	3.0	2.3
7 inches	6.8	6.4	6.0	5.4	4.9	4.2	3.5	2.6
8 inches	7.6	7.1	6.7	6.1	5.5	4.8	4.0	3.0
9 inches	8.5	8.0	7.4	6.8	6.1	5.3	4.4	3.3
10 inches	9.3	8.8	8.2	7.5	6.7	5.9	4.9	3.6
11 inches	10.2	9.6	8.9	8.2	7.4	6.5	5.4	4.0
12 inches	11.0	10.3	9.6	8.9	8.0	7.0	5.8	4.3
13 inches	11.9	11.2	10.4	9.6	8.6	7.6	6.3	4.6
14 inches	12.7	11.9	11.2	10.2	9.2	8.1	6.7	4.9
15 inchex	13.7	12.8	11.9	11.0	9.9	8.7	7.2	5.2
16 inches	14.6	13.6	12.7	11.6	10.6	9.3	7.7	5.6
17 inches	15.4	14.5	13.5	12.4	11.2	9.8	8.1	5.9
18 inches	16.2	15.2	14.2	13.0	11.7	10.3	8.5	6.2
19 inches	17.0	16.0	14.9	13.7	12.5	10.9	9.0	6.6
20 inches	17.8	16.8	15.6	14.4	13.1	11.5	9.5	6.9
21 inches	18.7	17.6	16.4	15.0	13.7	12.0	10.0	7.2
22 inches	19.5	18.3	17.1	15.6	14.2	12.5	10.4	7.5

The following figures and formulæ may also prove of value in preparing special volume tables from the data just given. The form factor of aspen is as follows:

Height	Form factor
40	0.43
50	.43
60	.44
70	.46
80	.52

The area of the base, multiplied by height, multiplied by form factor gives the total volume in cubic feet.

To convert solid cubic feet to stacked cubic feet, multiply by 0.7.

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